THE UNIVERSITY OF ALBERTA

SUITABILITY OF SOME SOILS IN THE EDMONTON AREA FOR ON-SITE SEWAGE DISPOSAL

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ABSTRACT

A surve of acreage households in the Edmonton area indicated th t more than 35% of these households had experienced ailure of their on-site sewage disposal system. Fai ures were more frequent on some soils than on others, part cularly those classified as Luvisols and those developed on fine-textured parent materials. Very little information hysical flow properties that could have predicted pr blem situations existed.

To bett r define the ranges of moisture movement properties o Edmonton area soils, infiltration and percolation ates were determined at twenty-five sites chosen to re resent a variety of soil types. Infiltration and percolat on properties were found to be related to the parent mater al texture and to the soil development. Fine-texture soils and Luvisolic soils had the slowest rates of inf ltration and percolation. Coarse textured soils and Ch rnozemic soils had rapid rates. These results concurred wi h the findings of the acreage survey, where the "slow" soils were associated with high rates of failure.

To dete mine some of the important combinations of soil and landscap factors that affect sewage disposal systems and to asses some of the suitability systems for sewage disposal, th soils and landscapes of two acreage subdivisions were mapped at a scale of 1:5,000.

One was located east of Sherwood Park on the Cooking Lake moraine and the other southwest of Edmonton in an area of sand dunes. The mapping units were distinguished on the basis of their soil development, parent material, landform, and dominant slopes. Hydraulic conductivity was determined for these soils in the field using an air entry permeameter (AEP) and on semi-disturbed cores. The usefulness of the AEP was also tested in this study.

This data was used as input to several suitability systems for on-site sewage disposal and the resulting evaluations were compared. The most valuable systems were those that not only defined the limitations at a site, but also specified corrective action.

The air-entry permeameter proved valuable in that it gave fast, reproducible results and used little water, thus making it more portable than most infiltrometers. However, it was also fragile and required greater care in field use.

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I. INTRODUCTION

The existance of a restricted development zone surrounding the City of Edmonton has led to the proliferation of country acreages, with individual holdings no smaller than one hectare. Ignoring the possibility of zoning changes due to the recent annexation of land to the City of Edmonton, the Edmonton Regional Planning Commission has estimated that 20% of the population growth in the Commission area in the next 20 years will be directed toward such acreage subdivisions.

The cost of providing services such as central water distribution and sewage collection and treatment for these scattered dwellings is usually prohibitive both for the landowner and the local municipal government. The landowner, then, with some guidance from provincial and municipal agencies, must shoulder the responsibility for finding a safe water supply and for disposing of his household wastes, usually on-site. Many, unfortunately, encounter difficulties.

In 1978, 293 acreage households in the Edmonton region were surveyed for the performance of their on-site sewage disposal systems (Gardiner, 1978). Their systems, most of which consisted of septic tanks connected to conventional percolation fields, had all met the construction and capacity standards set by the Alberta Department of Labour, Plumbing Inspection Branch (1977).

The survey discovered that more than 35% of these households had experienced some problem at one time or another with their sewage disposal systems, despite the fact that most had been operating for less than five years. The survey also found that precisely the same systems, having the same septic tank capacity and the same absorption field length and configuration, were often found constructed at different sites with widely differing sets of soil, landscape, and water use patterns. These systems worked well in some locations, but not in others.

Failures were more frequent for some soils than for others. This was related to parent material, where fine-textured materials were more often associated with failures than coarser materials. However, the nature of the soil development was also implicated. Luvisolic soils, on average, had greater failure rates than Chernozemic soils with the same parent material. The difference was especially striking for the till soils in the Edmonton area. A literature search revealed a paucity of information on the moisture flow properties of Edmonton soils that could have predicted problem situations. Field collected data was especially lacking.

Septic tank effluent can be safely and effectively treated by its passage through soil. It should be possible to provide proper treatment under almost any combination of soil conditions. The cost and technology necessary, however, will vary from site to site.

The success or failure of a sewage system can in part be attributed to its maintenance, but the prime considerations in designing a successful system must be the estimated load and soil and landscape factors. These should influence construction methods and will affect the cost of building a safe and efficient system. Currently in Alberta, the soil influence is mainly recognized through the use of the percolation test, which attempts to determine moisture flow rates through the soil. The necessary field size for effluent absorption is calculated from the percolation rate and the estimated household water use.

The objective of this study was to more fully define the suitability of some soils in the Edmonton area for on-site sewage disposal systems. To accomplish this, some of the more important combinations of soil and landscape factors that are limiting to the proper functioning of on-site sewage disposal systems in the Edmonton area were determined. In particular, moisture movement properties for a variety of Edmonton soils and various techniques to measure them were to be assessed.

Detailed field studies were conducted to assess the application of various interpretive systems for on-site sewage disposal. This was based on a field mapping program of two acreage subdivisions in the Edmonton area. These particular subdivisions were selected for the study since in the 1978 survey, both were found to include both successful and unsuccessful systems. The failures may have been

related to the applications of inappropriate techniques, but they could not be obviously attributed to faulty building materials or to negligence.

A final objective was to make recommendations on the collection and interpretation of soils data for the development of standards for on-site sewage disposal.

II REVIEW OF THE RELATED LITERATURE

1. SEWAGE TREATMENT BY ON-SITE SEWAGE DISPOSAL SYSTEMS

Most households in the study areas used sewage disposal systems consisting of a septic tank and an attached absorption bed or percolation field. In the septic tank, the sewage separates into liquid effluent, floating scum and solids which will settle out to form sludge. Treatment at this stage is anaerobic. The effluent is then guided out into the percolation field, which consists of a series of trenches in which are laid perforated pipe or weeping tile. The trenches should be no more than a metre deep to ensure adequate aeration, as this treatment stage requires aerobic conditions (Bouma et al., 1972). The effluent will be further purified as it passes into and through the soil. By the time it reaches the water table, the effluent should be clean enough to drink.

This kind of system has been in existence in its most basic form for several hundred years. The first subsurface irrigation system for sewage disposal began operation in 1559 in Prussia and was still functioning 500 years later (Webber, 1974). Most of the septic tank/filter field systems do not have that kind of longevity, but if well-constructed, adequately sized, and properly maintained, such systems will have an average half-life of about 25

years (Hill and Frink, 1980), and up to as much as 60 years (Clayton, 1975).

Technically, a system failure can be said to occur when septic tank effluent is consistently applied to the soil-percolation field interface at a rate greater than it can be accepted and transmitted by the soil body. That is, the effluent is applied at a rate greater than the permeability or hydraulic conductivity of the soil. A failure can also be said to occur if the residence time in the unsaturated, unconsolidated portion of the soil is less than that required to purify the effluent. This is usually considered to be the case if lithic contact or the permanent or seasonal water table is within one metre of the trench bottom. This is especially important where the soil permits the very rapid through-flow of moisture.

When a system fails because of slow infiltration and overloading, the effluent will pond in the field and result in anaerobic, saturated conditions where the purification process takes much longer than in unsaturated conditions. Ultimately, the effluent may break through to the surface, or back up into the house basement. When failure occurs as a result of shallow unconsolidated and unsaturated material, non-purified effluent may be injected into local ground water supplies, or may move laterally along an impervious layer, later emerging as an effluent spring.

Other kinds of systems do exist. Some are designed primarily to cut costs, and are potential hazards, such as

some leaching cesspools. Others, however, are used to overcome difficult sets of soil conditions. These include mound and raised bed systems, which will be described more fully later. In some areas, where potential evapotranspiration rates are very high, the bottom of the percolation field can be sealed off with material impermeable to water so that all moisture flow is upward. This type of system is not recommended for locations as far north as those in central Alberta, because of the short warm season. The evaporation beds, where possible, do provide a viable alternative to the more conventional systems, especially for sites with high water tables or with near-surface impermeable layers (Winneberger, 1974).

In northern latitudes, such as that of central Alberta, freezing of the filter field may seem probable. However, unless the snowcover is very thin or has been compacted by foot or vehicular traffic, system freezing is actually quite rare. Viraraghavan and Warnock (1973) monitored a system in northern Quebec over a year and found that temperatures within the drainage tile were constantly above freezing. Systems in Alaska were examined in another study (Hickey and Duncan, 1966) and these were likewise found never to freeze. Trampling the snowpack, though, may so increase its thermal conductivity that the field may freeze and be unusable until it thaws with the return of warm weather.

When the effluent seeps out of the trench line and into the soil, it consists of fatty acids, bacteria, amino acids,

nitrates, ammonia, phosphates, hydrogen sulfide and water. As it moves through the soil it will be purified by chemical, physical, and biological means. Physical removal of suspended solids by straining, adsorption and sedimentation is important, but this also reduces the size of soil pores and channels. This often inhibits the efficiency of the system, but in the case of very sandy soils may be beneficial (Machmeier, 1981).

The bacterial population of the effluent includes essentially the same suite of organisms that is found in the human intestinal tract, many of which may be pathogenic. The soil body, though, is a hostile environment for these bacteria and with time they will die off (Reddy et al., 1981). In unsaturated soil layers the organisms will move only a few centimetres from the source. In saturated soils, they can move much farther (Reneau et al., 1975).

Whether saturated or unsaturated, the degree of retention of the organisms is inversely related to the size of the particles making up the soil matrix. The finer the matrix, the greater the retention will be, mostly by physically straining out the organisms. In zones of saturated flow, sedimentation of bacterial clusters will occur. Adsorption of bacteria onto charged particles becomes increasingly important as clay content increases. Under unsaturated conditions with long retention periods, the organisms will die. Thus, both physical removal and inactivation of the organisms affect the purification of the

effluent (Reddy et al., 1981).

A potential for viral contamination of groundwater also exists. However, the present state of knowledge of the kinetics and activity of viruses is largely based on studies of soil columns. Adsorption does appear to be the most important removal mechanism for these very tiny charged particles, but the exact mechanism is not known (Reddy et al., 1981).

Another concern is that the viral particles may remain active even while they are adsorbed, and that they may be released if eluted (Hagedorn et al., 1981). Lance et al. (1976) found that polio virus could survive almost 100 days in sand flooded with waste. When deionized water was applied, the viral particles were desorbed.

The nitrogenous compounds (amino acids, nitrates and ammonia) are metabolized by bacteria. Organic phosphates may also be utilized by bacteria in the soil, but inorganic phosphates will combine with calcium, aluminum or iron, form insoluble compounds and precipitate out of the soil solution (Lance, 1977).

The potential hazards are not limited to the transmission of water-borne pathogenic organisms. The contamination of groundwater by high amounts of nitrate can lead to a very serious condition in infants known as methemoglobinemia. While not usually a hazard to human health, nitrogenous and phosphatic components introduced into surface water bodies may result in algal blooms and

consequent oxygen depletion and eutrophication of the water body (Alexander, 1977).

If the depth of unsaturated, unconsolidated material below the trench line is great enough, then enough of these contaminants will be removed for the liquid to safely become part of a groundwater pool. The depth that is necessary depends on the soil. In sandy or gravelly soils, the liquid will pass through very quickly, as the pore spaces are large. There will be less physical straining of the effluent than in finer soils. This rapidity of flow may mean that the field will never or rarely be saturated, but it may also mean that the effluent has not had adequate time to become purified before it reaches the water table (Bouma, 1974). Intestinal bacteria may not yet have died and metabolism of the organic compounds may not have occurred. There is less surface area in sandy soils than in clay soils, and unlike many clay minerals, sand-sized particles have low surface charge. This means that other charged particles, such as bacteria and viruses, will not be adsorbed to the same extent in these soils as in clay soils.

In soils with high clay content purification of the effluent may be impeded because flow around these microscopic particles is very slow. Passages may also become blocked by material contained in the effluent. The clay particles themselves may swell, absorbing water into their structures, and close off pores. Unless effluent is added very slowly, the soil will become saturated, and

purification proceeds much more slowly. The ability of a soil to accept and transmit water is thus a very important aspect to consider in designing a system.

2. MOISTURE FLOW

Moisture moves through a porous medium such as soil in response to driving forces. These driving forces are differences or gradients of elevation and of water pressure. In saturated soils the water pressure is positive, and is expressed most simply as the depth of a point in question below the surface of the water table. This depth is known as the pressure potential of water at that point.

If the soil is unsaturated, then energy must be expended to withdraw moisture from the soil. This is a negative water pressure, known as matric potential, or also as suction or tension. This potential is usually expressed in the dimensions of a distance or length. Any point in a soil has a particular gravity potential based on its elevation above or below a reference datum level. The datum level location will not affect the gravity gradient that would be calculated, since only the elevation differences are considered.

In a saturated soil, the flow of water from one point to another in one direction can be described by Darcy's Law as:

$$q = -k \frac{dH}{dz}$$

where q is the moisture flux in centimetres per second; this is a velocity. The quotient dH/dz is the hydraulic

gradient. The term, dH, is the change in total soil water potential, including matric or pressure potential and gravity potential. This change in potential is divided by the distance (dz) between the two points, in this case in the vertical (z) direction. The proportionality constant, k, is the hydraulic conductivity, and this also has the units of velocity, cm/sec. The equation is made negative as the flow is in the direction of decreasing potential.

This equation is subject to several conditions. As it is written, the equation only describes systems where conditions are saturated; flow is in one direction only; temperature is assumed to be constant at all points; and flow is assumed laminar rather than turbulent. That is, adjacent volumes of fluid move in a regular manner with respect to each other (Hillel, 1971).

When the soil is unsaturated, hydraulic conductivity will change. As the moisture content or the soil water potential decreases, hydraulic conductivity also decreases. The effective cross-sectional area for liquid flow is reduced by the presence of air in some pores. Also, the tortuosity and hence the length of the path that a particle must follow to get from one point to another is increased (Hillel, 1971).

Hydraulic conductivity decreases rapidly as the soil begins to dry, but changes less and less as drying continues. The pores that empty first are the largest

pores, the pores that permit the most rapid fluxes. Loss of these pores from the flow system affects hydraulic conductivity. Also, certain channels and pores may be divorced from the continuous network by air bubbles. These isolated, unconnected pockets of air further reduce the hydraulic conductivity (Hillel, 1971).

The relationship between hydraulic conductivity and moisture content or matric potential varies from soil to soil; each situation is unique. Hydraulic conductivity is influenced both by texture and structure of the soil. Texture influences not only total porosity, but also pore size, which is critical to determining hydraulic conductivity. Thus a clay soil, with high porosity but very fine pores, will have a lower conductivity than a sandy soil with lower porosity, but larger average pore size. Hydraulic conductivity is commonly 10^{-2} to 10^{-3} cm/sec for sandy soils, while for clay soils it ranges from 10^{-4} to 10^{-7} cm/sec (Hillel, 1971).

In strongly pedal soils (soils with strong structure) hydraulic conductivity is generally greater than in non-pedal soils. Structure has been defined as "the physical constitution of a soil material as expressed by the size, shape, and arrangement of the solid particles and the voids. Particles include both the primary particles that form compound particles and the compound particles themselves" (Brewer, 1964).

In saturated soils, much of the moisture flow occurs

along large channels or macropores that may include interpedal voids, root channels and worm holes. Hillel (1971) believed that such macropores would not transmit water if the soil was not saturated. Other authors (Thomas and Phillips, 1979) disagreed, and observed that gravitationally induced water flow could occur in macropores while the moisture content of the soil was well below field capacity.

Hillel's viewpoint is consistent with the theory of piston-like infiltration of soil water. According to this, a distinct wetting front will appear, and the maximum soil moisture content will approximate field capacity. Thomas and Phillips (1979), though, note that the degree of this simple, piston-like flow will depend on the degree of structure and on the rate of water addition. For example, if there is strong structure and sudden addition of water, then nearly all the water will flow through the macropores. The soil matrix will wet up more slowly by radial movement of moisture out from the macropores.

Later, Hillel (1980) recognized that complications will arise when water is introduced to soils that experience shrinking and swelling, especially when cracking occurs. In these, the soil will behave as separate columns. Infiltration and flow in such soils, where the cracks may be very deep, will be very different from the orderly one-dimensional process. With reswelling, the cracks close and the columns coalesce. Until this happens, though, the

surface zone will be bypassed, as the water moves directly into the cracks to be absorbed at greater depth.

The potential for this rapid flow through macropores to deep levels can have some serious implications for contamination from percolation fields because of the short residence time in the soil. Effluent may at times be able to move to considerable depths. However, it would be unlikely that the soil beneath a percolation field would be dry enough to show such cracking. Contamination of ground water would be more likely in soils having strong structure, but lacking significant amounts of swelling clay.

Darcy's Law as stated applies to a homogeneous medium. However, layered situations such as the solum, can be handled by treating each layer or horizon as a separate homogeneous medium with a new set of boundary conditions for each.

The presence of layers with dramatically different hydraulic conductivities almost always results in the reduction of the total flow through the system. A "slow" layer beneath a "fast" one cannot accept and transmit quickly, and thus reduces overall conductivity. A "fast" layer beneath a "slow" one also experiences reduced flow. The "slow" layer will not be able to supply enough moisture to keep the underlying layer saturated. The unsaturated conductivity of the "fast" layer is less than its saturated conductivity, and overall conductivity through both layers is again reduced.

3. INFILTRATION

Infiltration is the term used to describe the entry of water into the soil at some interface with the surface. The rate at which water enters the soil is the infiltration rate and is equivalent to the flux term (q) in the Darcy flow equation.

If water is supplied to the soil surface at a gradually increasing rate, eventually a critical rate will be reached such that the surface cannot absorb the water as quickly as it is added. If water is added to the surface at a rate slower than the critical rate, then the infiltration rate will be controlled by the rate of supply. If the critical rate is exceeded, then the excess water will pond in depressions on the surface or will run off downslope.

If a shallow layer of water is added and maintained at the surface, the infiltration rate will not remain constant as time passes, but will instead decrease. The initial value is a function of initial moisture content, texture, and structure. The infiltration rate decreases monotonically and asymptotically approaches a constant value as time goes on. This value is the final infiltration capacity and is independent of the initial moisture content (Hillel, 1980).

The decrease in the infiltration rate may be partially attributed to sealing of the surface by swelling clay particles, air entrapment, or pore blockage by transported

particles. However, most of the decrease is due to the decrease in the driving force to water flow, the matric potential gradient. Initially there will be a very strong gradient between the wetted surface and the drier soil beneath. As the wetted zone deepens and the liquid redistributes itself, the matric potential differences will become very small, or disappear altogether. In a horizontal column of soil, the infiltration rate will tend toward zero. In a vertical column, steady flow will occur at a rate controlled by gravity. When the profile is homogeneous and structurally stable, this rate will approximate the saturated hydraulic conductivity (Hillel, 1980).

When septic tank effluent is applied to a soil surface, the final infiltration capacity will be less than that for pure water because of the development of a physical barrier on the base and side walls of the trenches. This barrier is a biological crust or mat, which develops under persistent conditions of saturation (Bouma et al., 1972). It forms by pore blockage, by the straining out of large particles, or by compaction and smearing of the trench surfaces during construction. Ion exchange may also be a factor in that low concentrations of sodium, such as may be introduced by water softening, may lead to the dispersion of clay aggregates. The clogging may also be enhanced by the swelling of the clay-sized particles.

The most important factor, however, in the formation of the biological mat is the development of a slimy black concentrate of organic matter and associated mineral

colloids and microorganisms. This biological clogging is the result of bacterial growth and the accumulation of nutrient substrate in the soil pores (Bouma et al., 1972). The responsible bacteria are anaerobes found in the effluent. These are able to survive because the soil in the trench is being continually inundated. A by-product of this biologically active layer is ferrous sulphide which is insoluble and also plugs the pores.

Where the soil is naturally well drained, the horizons below the impeding clogged zone will be unsaturated and hence the flow through them will be less than through the soil when saturated. In a sand beneath a clogged mat, the flow may only be one percent of the saturated flow through the same sand (Tyler et al., 1978).

The existence of this mat may be an advantage under certain circumstances, such as in sandy and gravelly soils with excessively high hydraulic conductivities. Since flow beneath the crust is much slower, there will be greater opportunity for close contact between the effluent and the soil particles. There will be time for reactions to occur at the particle surfaces and in the air-soil solution interfaces. The crust may also reduce the rapid macropore flow, allowing better treatment. However, this effect will only be felt after a year or two of system operation (Simmons and Nowland, 1973). Even then, unless the crust develops evenly, the effluent load may simply be transferred to uncrusted parts of the percolation field.

4. FIELD MEASUREMENT OF SOIL MOISTURE MOVEMENT

Many different techniques and devices are available for the measurement of hydraulic conductivity and infiltration, and several can be used to determine both. In the course of this study, three different field techniques and two different laboratory techniques were used. A brief summary of some of the various approaches therefore is in order.

For flooding type infiltration rate techniques, the plot area is bounded by a wall of some impermeable material so that water can be ponded above it. A constant head is maintained at the surface while the rate of water use required to maintain that constant head is recorded as the water intake. Evaporation, under most conditions, is considered negligeable.

The cylinder type is the most common flooding infiltrometer. It exists in a variety of forms and sizes. Single and multiple concentric cylinders, weighing lysimeters and drainage lysimeters are all used. The single cylinders are easily managed by a single operator and are cheaply manufactured. However, the rate of water intake per unit area will vary markedly with the size of the cylinder, decreasing as cylinder diameter increases. This is caused by the decreasing effect of the lateral movement of water as diameter increases. Graphical and statistical techniques (Hills, 1971; Tricker, 1978) are available to correct for lateral flow.

Other researchers have circumvented this problem by using double or concentric cylinders, with intake measured in the inner ring. Water is maintained at the same level in the outer ring as in the inner, to act as a buffer zone.

The double ring infiltrometer has been used in association with multiple-depth tensiometers (Ahuja et al., 1976). The tensiometers permit the determination of hydraulic gradients below the installation. Once these are known, the vertical and lateral flow components can be assessed, along with saturated hydraulic conductivities for each soil horizon.

Bouwer (1961, 1962) was able to determine the vertical components of saturated hydraulic conductivity by using the double ring infiltrometer and manipulating the water levels in both the inner and outer tubes. Hillel and Gardner (1970) suggested modifications to this apparatus so that unsaturated hydraulic conductivities could be measured in situ. For this procedure, sand and gypsum crusts were applied to the surface of a carved out soil column that was encased to prevent any seepage. A measured head of water was then maintained at the surface, resulting in unsaturated conditions below the crust at a tension monitored by tensiometers. The rate of water intake could be directly related to unsaturated hydraulic conductivity at that particular soil moisture tension.

In the pump-in well technique, saturated hydraulic conductivity (K_{sat}) is found from the rate of flow of water

out of an auger hole. The hole is dug to the desired depth, filled with water and maintained at an arbitrary depth until flow into the soil becomes constant. This test measures K_{sat} in a horizontal direction. Several days of pumping may be necessary before equilibrium flow is maintained. According to Bouwer and Jackson (1974) in the order of a cubic meter of water may be required for the test.

For the cylinder permeameter method, infiltration gradient method, and the air entry permeameter method, hydraulic conductivity is found from the vertical infiltration rate and from a measured hydraulic gradient.

For the cylinder permeameter, an infiltrometer of fairly large diameter (50 cm) is installed in a hole dug to the depth of which it is desired that K_{sat} be known. Tensiometers are installed with the ceramic cups at about 20 cm below the soil surface. Water is applied to the cylinder and maintained at a depth of about 15 cm. Saturation is assumed when the tensiometers indicate a pressure head of zero. The infiltration rate is measured at this time, before positive pressures can develop. The hydraulic gradient is calculated from the water depth in the cylinder and the depth and pressure head of the tensiometers. K is then calculated from the Darcy flow equation. The test requires several hours to set up and run, and several hundred litres of water.

The infiltration gradient technique is a modification of the cylinder permeameter method. Two concentric rings

are installed in an auger hole, and small, fast-acting piezometers are pushed into the soil by increments so that the complete vertical hydraulic gradient may be obtained. In this way, the vertical flow in the soil below the hole can be determined, and the effect of surface sealing of the soil on the measured value of K can be eliminated.

When the air-entry permeameter is used, hydraulic conductivity is derived from the Darcy flow equation. The technique, as first developed by Bouwer (1966) required as input an infiltration rate obtained under high head, and a hydraulic gradient measured indirectly by observing the depth of the wetting front. The air entry pressure at the base of a wetted column of soil is used to estimate the water entry pressure at the wetting front. The water entry pressure will always be less than the air entry value because of hysteresis (Bouwer and Jackson, 1974).

A cylinder is driven into the soil and then covered by a plate with a vacuum gauge and a standpipe and reservoir. Water is applied to the soil surface, while the air above the soil surface is vented through a purge valve. With the cylinder full, the purge valve is closed, and the reservoir kept full to maintain a head of water of between 50 and 100 cm.

When the wetting front is expected to have reached the lower end of the cylinder, the infiltration rate is determined by stopping the supply of water to the reservoir and measuring the rate of fall of water in it. The supply

valve is then closed, in effect freezing the position of the wetting front. The water pressure inside the cylinder will become negative, reach a minimum, and then begin to increase as air bubbles up through the wet soil into the cylinder. The minimum pressure head is recorded by the vacuum gauge.

To determine the air-entry value, the minimum pressure head must be referred to the position of the wetting front. Originally, this was determined by pushing a rod into the soil and noting where the penetration resistance began to increase, or by digging into the soil to observe the wetting front visually. Either way, the soil must be quite dry before the test is run.

Topp and Binns (1976) introduced a major modification in the form of a small diameter, fast-response tensiometer probe. This is inserted through the cover plate to a known depth. As the wetting front passes, the tensiometer reading will suddenly decrease. The water supply is then cut off, and the air-entry value determined. The depth to the wetting front can thus be more accurately measured. It is also possible to carry out the test in much moister soils than where direct observation of the wetting front is required.

So long as the wetting front has not advanced very far beyond the bottom of the permeameter cylindar, one dimensional flow can be assumed to prevail, and the air entry value and K can be calculated from:

$$P_a = -P_{min} + G + L$$

$$K = \frac{dH}{dt} \cdot \Delta Z \cdot \frac{Rr^2}{Rc^2} / (H_t + \Delta Z - 1/2Pa)$$

where: P_a is the air entry value

P_{min} is minimum pressure in cm H_2O as determined by the maximum reading on the vacuum gauge.

G is the height of the gauge above the soil surface.

ΔZ is the depth to the wetting front in cm.

$\frac{dH}{dt}$ is the rate of fall of the water level in the reservoir just before closing the supply valve.

Ht is the height above the soil surface of the water level in the reservoir when the supply valve is closed.

Rr is the radius of the reservoir.

Rc is the radius of the cylinder.

The water entry value, which is the pressure head at the bottom of the wetted zone during infiltration, is estimated by taking one half the value of P_a.

The value of hydraulic conductivity calculated here will always be less than K_{sat} because of air entrapment. Bouwer (1966) estimates that it is one-half the value of K_{sat}. Topp and Binns (1976) found good agreement between laboratory determinations of K from undisturbed cores and those calculated from the air-entry permeameter. The test takes from half an hour to a few hours to complete and only requires about 10 litres of water. The combined speed, accuracy, and low water requirements favor this method

over other methods.

Another water movement test is the percolation test. This test was first devised by Henry Ryon in the 1920's to determine allowable effluent application rates to soil. Results of this test are required by law in many jurisdictions before installation of a sewage disposal system will be permitted. Theoretically, though, the test does have some serious flaws.

The test has many variants, but according to the Alberta Department of Labour, Plumbing Inspection Branch (1977) a cylindrical hole 20 cm in diameter should be augered to a depth of 100 cm. Water is added to the auger hole and maintained in it until the surrounding soil is saturated. The time required for the water level to drop one centimetre is monitored until the rate of drop becomes constant. This constant drop rate is known as the percolation rate.

As Anderson et al. (1978) comment, the percolation test measures the rate of flow from a hole dug in the ground. This rate depends not only on the hydraulic conductivity of the soil, but also on the shape of the hole, the depth to water table, and the moisture content of the soil around the hole. None of these is parameters measured independently as the test is carried out. Thus, the relationship between hydraulic conductivity and the percolation test is not clear.

The test results can also be manipulated by conducting

the test during dry weather. These rates will be very different from those of a test carried out on the same soil during a wet season. However, the simplicity of the test makes it very attractive. When conducted in the wet season, with the water table at least 6 m from the bottom of the hole, the test results can be used to estimate the required absorption field size (Anderson et al., 1978). By itself, though, the percolation test is not an adequate measure to determine the suitability of a site for effluent disposal (Parker, 1977).

5. EVALUATION OF LAND FOR ON-SITE SEWAGE DISPOSAL

In the past, proposed sites for sewage disposal have been evaluated in many ways. Allowable ranges of soil and landscape properties have been established under some schemes, using a pass/fail approach. In other systems, where regional planning is the concern, areas may be rated as limited for sewage disposal. Still others attempt not only to assess the limitations in an area but also to define corrective measures and costs.

On-site sewage disposal systems can be installed more successfully and more cheaply on some sites than on others. For the sites with conditions less appropriate than the ideal, special design considerations can overcome most difficulties, but at a cost.

Among the factors that should be considered in a site evaluation are the area requirements, landscape characteristics, geographic considerations, geological (chemical, physical, and structural) characteristics, soil characteristics, topography, and groundwater patterns (Parker, 1976). The author considers texture, changes in texture with depth, structure, color, color patterns, and bedrock conditions to be the important soil profile characteristics. Other important soil properties to assess are hydraulic conductivity or permeability and Atterberg limits. The latter would give an indication that special construction techniques might have to be used (Machmeier, 1981).

The required field area will be least on stable, gently sloping surfaces that are not subject to flooding. At least 180 cm of well-drained permeable soil, free of coarse fragments, should overlie a consolidated or saturated layer. The required area increases as slope increases and solum thickness, depth to groundwater, or permeability of the soil decreases. The area requirements will also, of course, depend on water use and number of people of the household, and hence the expected load (Alberta Labour, 1977).

Landscapes that show evidence of downslope mass movement should be avoided. Floodplains and slopes associated with springs and seeps are also unsuitable. Slopes of more than twenty percent will be difficult to deal with and certain slope forms are more appropriate than others as runoff will be more rapid from convex slopes than concave slopes (Parker, 1976).

For the geographic considerations, an estimate should be made as to whether the future population density of an area will be substantially greater than the present. A marginal site may be approved because the present population is sparse, but problems may appear as the population density increases (Parker, 1976).

Important geological characteristics include the physical and chemical characteristics of the bedrock, its structural properties, and the regional topography. If the effluent is not sufficiently purified in its passage through

the soil, then the ability of the bedrock to purify effluent should be considered. It should have permeability within the proper range, and faulted or jointed bedrock should be avoided, since this may allow effluent to pass through without undergoing any purification at all (Parker, 1976).

The dominant direction of groundwater flow (whether the site is in a recharge or discharge area) must be established. Areas of discharge, where water is moving upward, may not allow adequate treatment. The seasonal height of the groundwater table should be determined. This is most easily done by examining the soil for the presence of mottles or gleying. Dull or grey colors signify extended period of saturation, while mottled grey and brown or rusty colors show alternating periods of saturation and aeration (Machmeier, 1981).

The Manual of Septic-Tank Practice, developed by the U.S. Department of Health, Education and Welfare (1969), has had a strong influence on site approval procedures in many jurisdictions in the United States and Canada. According to the Manual, a site is suitable for on-site sewage disposal when:

i) the capacity of the soil to transmit liquid is expressed by a percolation rate of no slower than 60 min/inch or 24 min/cm;

ii) at least 90 cm of unsaturated soil must be present between the bottom of the trench and lithic contact or groundwater. The groundwater level may

be within this range only at the wettest time of year. Mottling is sometimes permitted as an indication of periodic saturation;

iii) slopes must not be excessive, nor should the site be located on a floodplain where it is subject to frequent inundation.

Slight variations to these guidelines have been developed. For example, a lower limit is also often placed on the allowable percolation rates to avoid excessively rapid flow of the effluent through the soil. Most often, this limit is placed at 2 min/cm, as in Ontario (Environmental Protection Act, 1971).

The major problem with this approach is that it is a pass/fail system, and apparently does not recognize that corrective action may be possible in some cases, although perhaps at some extra cost.

The U.S. Soil Conservation Service uses the concept of limitations in determining site suitability for septic tank absorption fields. The criteria are stated in Table 1, and are essentially similar to those given by the USDA. The overall goal is to give uniform meaning to the slight, moderate, and severe ratings assigned to soil series. These ratings usually appear as tables in soil survey reports. The ratings do not take the place of site-specific information, but will be especially helpful in planning for development.

Soils with slight limitations have properties well suited to use for effluent disposal. Soils with moderate

TABLE 1. Ratings of soils for effluent disposal in septic tank seepage fields according to the U.S. Soil Conservation Service (modified after Olson, 1981)

	Soil limitation rating		
Factor affecting use	Slight	Moderate	Severe
Permeability class	Rapid, moderately rapid	Moderate	Moderately slow, slow
Water Conductivity rate	>2.5 cm/hr	1.5-2.5cm/hr	<2.5cm/hr
Percolation rate in auger hole	> 18 min/cm	18-24 min/cm	< 24 min.cm
Soil drainage class	Well drained, moderately well drained	Somewhat poorly drained	Poorly drained, very poorly drained
Flooding	None	Rare	Occasional or frequent
Slope	0-8%	8-15%	>15%
Depth to hard rock or impermeable layer	>1.8 m	1.2-1.8 m	<1.2 m
Stoniness and rockiness	None	Some	Many

limitations are moderately favorable. The limitations can be overcome or modified by special planning or maintenance. Soils with severe limitations have one or more unfavorable soil properties for waste disposal. These limitations will be difficult and costly to overcome. For some severely limited soils, it may not be possible to overcome the limitations.

This approach and these criteria have been widely applied in American soil surveys, and also in several Canadian studies (Simmons and Nowland, 1973; Greenlee, 1973; Greenlee, 1976; Coen and Holland, 1976). Other modifications have also been made to it. For example, in the Soil Survey of Waterton National Park (Coen and Holland, 1976), an "unsuitable" category was added for mapping units where it was physically impossible or economically impractical to use the soil for septic tank absorption fields. Such areas had at least one of the following characteristics: slopes greater than 30%, very low permeability, annual or more frequent flooding, or depth to hardrock, bedrock, or other impervious material less than 24 inches.

In some of the older American soil surveys, inconsistencies have been noted between the properties of some soil series and the ratings applied to them. These do not match the ratings that would be given by strictly adhering to the guidelines (Gordon and Gordon, 1981), largely because of interpretation by the mapper. Analysis

showed that the guidelines were more conservative than the series ratings, but overall agreement was very good. More recently, there has been greater consistency in the interpretations since data files for each soil series are now established and consulted as they are mapped (Gordon and Gordon, 1981).

Simmons and Nowland (1973) produced an interpretive map of the soils of Nova Scotia for planning for septic tank system installation. They recognize eleven suitability categories, each of which is associated with a different combination of limiting situations. The map also indicates the likelihood of randomly selected sites to be affected by any of the limiting situations. Table 2 is a summary of the categories, limitations, and probability ratings of the system. The authors have deliberately avoided use of the "slight, moderate, severe" terms since they recognized that modern technology was capable of developing sound systems under most sets of circumstances.

The probability ratings indicate that, for example, in Category 1, with an 85% suitability rating, 3 out of 20 random locations will be unsuitable for some reason. For category 5, soils over 90% of the area can be expected to have percolation rates slower than the accepted standards. Ninety percent of the area, not necessarily coincident with the other 90%, is subject to prolonged periods of high soil moisture.

TABLE 2: Soil limitation categories for septic tank disposal systems in Nova Scotia (modified after Simmons and Nowland, 1973).

Suitability Category	Area	No limitation	Percolation rate too slow	Bedrock within 2 m of surface	Prolonged saturation	Periodic saturation	Excessive percolation rate
1	8.1%	85%					
2	4.4%	50%		50%			
3	3.4%*		90%				
4	8.8%		80%			80%	
5	2.3%*		90%		90%		
6	4.1%		90%	50%			
7	49.7%			85%			
8	8.6%			80%		90%	
9	3.0%			80%	90%		
10	2.6%*						80%
11	0.2%*					90%	80%

*Additional areas subject to flooding: 3-0.27%, 5-0.5%, 10-0.46%, 11-0.06%.

The criteria for the limiting factors are consistent with the USDA and US Soil Conservation Service guidelines. These are, in fact, the regulation, according to the Nova Scotia Department of Health (Simmons and Nowland, 1973).

The system was scaled to 1:50,000 maps, and also generalized to 1:250,000 to show gross trends and relationships. The main function of the smaller scale map is as an educational tool. At 1:50,000, the delineations cannot show individual lots, as the average minimum delineation would encompass about 25 ha. However the maps indicate to Public Health Inspectors the kinds of limitations that they can expect to find. Simmons and Nowland (1973) reported that the Nova Scotia Department of Health had, at the time of publication, requested that these 1:50,000 map sheets be made available to health inspectors in the province. The authors hoped that the use of the maps would reinforce the decisions of health inspectors when they rejected applications for marginal or unsuitable sites.

Bouma (1974) used a similar approach in Wisconsin, but took it a step further. Once the kind and severity of limitations that a site might have are defined, specific alternative "construction and management packages" are prescribed to overcome them. Figure 1 illustrates some of the limiting situations and the corrective action.

In the event of thin, permeable soil overlying creviced bedrock (situation 1), pathogenic well-water pollution could easily occur if a conventional system is used. To prevent

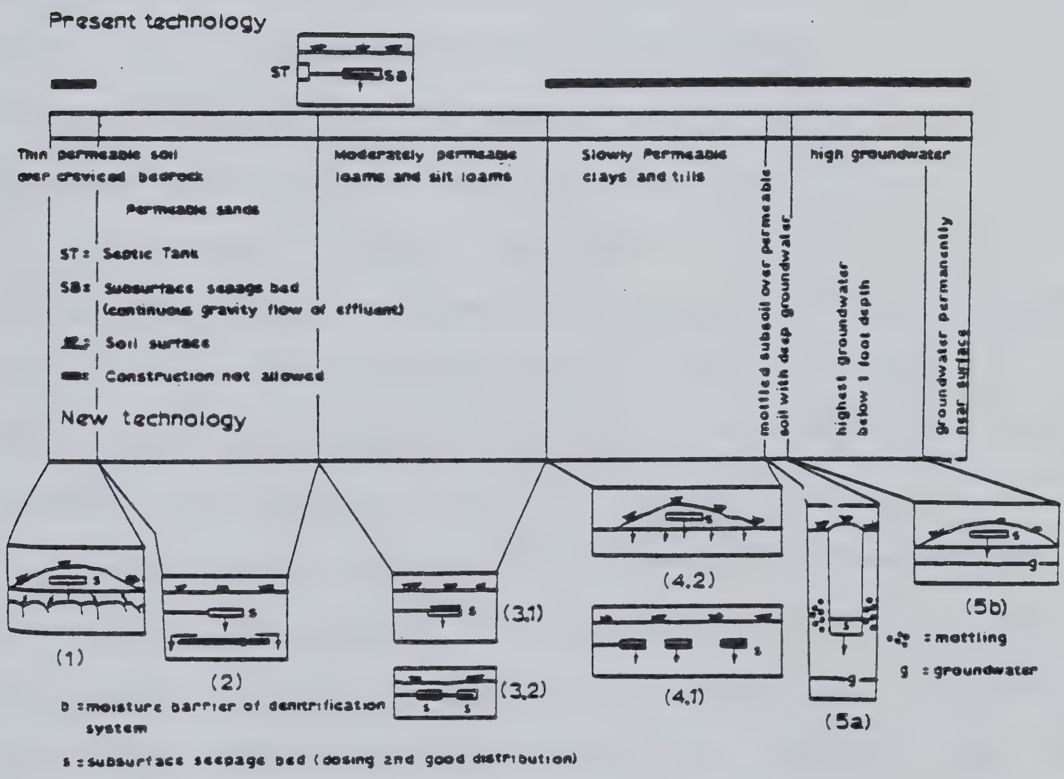

Figure 1. Schematic diagram of on-site disposal systems of septic tank effluent, comparing present and new technology (modified after Bouma, 1974).

this, a seepage bed can be installed on top of 60 cm of sand fill placed on the soil surface. Such a mound system can also be used to overcome the limitations of slowly permeable soils where the water table is no closer to the surface than 30 cm (situation 4.2). This will prevent the possibility of puddling of the soil surfaces during excavation, and also avoids the problem of excessive obstruction of flow into loamy and clayey soils by biological clogging.

For areas subject to high groundwater levels (situation 5b), the situation may again be improved by raising a mound above the surface and installing the system in it. Alternatively, it may be possible to artificially drain the surrounding area and thereby improve conditions.

Management is also a consideration. Reduction of biological clogging can be achieved by allowing the system periods of aeration (situation 3). In an oxidizing environment, the clogging components will break down and permit freer moisture flow.

Bouma also suggests that it should be possible to extrapolate the rating from one site to others with key soil properties similar to those of the first site. He proposes three approaches to do this. The first requires that these key properties be emphasized and evaluated at experimental sites where the innovative disposal systems are being tested. The same key properties would then be assessed at each future site, and rated in comparison with the experimental sites.

A second approach is to compare the taxonomic classification of the two sites. If they are the same, then it is assumed that it should be possible to extrapolate the technology used at one site to the other.

In the third approach, the key properties of sites in mapping units named for the same soil series are assumed to be identical.

The key properties used in the first approach were hydraulic conductivity characteristics, occurrence of groundwater, and site factors such as slope and landscape form. For extrapolation to any new site, hydraulic conductivity curves (relating K to a range of moisture content and tensions) would be necessary. This is an effective, but time-consuming procedure.

The assumption that key soil properties of a site can be adequately estimated by extrapolating measured values of these properties from another site with the same taxonomic classification is partly realistic. Groundwater and bedrock levels are included in soil series definitions. However, hydraulic conductivities for different pedons in the same soil series may vary widely. Textural differences that could impede or obstruct absorption may appear at depths exceeding 1.5 m, and would not be represented as a phase of the soil series.

When the series or the phase is well characterized and where detailed information on the variability of the key properties is known, then use of this extrapolation method

should be quite successful. The soil at each site would have to be classified according to the accepted taxonomic scheme (U.S. Soil Taxonomy, in this case). Property variability for the series would need to be assessed. If sufficiently low, then direct interpretation might be possible without actually testing at the site. When the property variability is very low, the soil series or phase could be directly associated with certain system types.

The third extrapolation technique should be acceptable only if mapping units contain few inclusions. This, according to Bouma (1974), means that nearly all of the delineated areas will consist of soils that fall within the definition of only one series. The variability of properties within mapping units is not usually well-known, despite being assessed more commonly now than in the past. Scale is also a problem since, except for very detailed maps, units of less than one hectare cannot be shown. The absorption bed areas, though, are only about 90 m^2, or .01 ha.

The use of the taxonomic extrapolation would be more economical than actual measurement of the soil properties. Soil maps can be used if they are fairly homogeneous. However, the variability of the properties should be better known before they are used for regulatory purposes or for demonstrating the impact of new technologies on land use patterns.

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Service (Machmeier, 1981) uses a very site-specific approach. The Extension Service has produced and distributed clear and comprehensive information and instructions on the proper design, installation, use, and maintenance of on-site sewage treatment systems. It is intended to present treatment solutions for all combinations of soil and site conditions likely to be encountered in the north-central United States. It avoids designating areas as being slightly, severely, or moderately limited; rather the alternative construction requirements for different sites of conditions are offered.

Other evaluation techniques attempt to determine not only soil ratings and construction methods, but also the cost of the construction. McCormack and Johnson (1982) report on the determination of soil potential ratings for onsite sewage disposal in Leon County, Florida. The soil potential ratings are classes indicating the relative quality of soils based on their performance when feasible corrective measures are used to overcome the soil limitations. Performance levels, the cost of applying the modern technology to minimize the limitations, and the longer term adverse effects of the soil limitations after the technology is applied are all considered by a team of soil scientists and local experts. The soil scientist identifies the properties of the soil and makes certain that the local team of experts understands them. The local experts make all other decisions.

A systematic procedure is used to establish the soil potential ratings. These are expressed in a five-class system: very high, high, medium, low, and very low. A soil potential index is calculated for each soil and classes are assigned to selected ranges of the numerical SPI. The SPI (soil potential index) is calculated from SPI = P-(CM + CL), where P is the performance standard, CM is the index of costs of corrective measures, and CL is the index of costs resulting from continuing limitations.

To determine the ratings, the team follows a series of steps in a fixed sequence:

1. Define land use. This establishes P, the performance standard, by defining the specifications, including cost, of the standard septic tank absorption field installation in Leon County, Florida. For the standard three bedroom house, a 900 gallon septic tank with distribution box and 400 sq. ft. of absorption field, at an installed cost of $800 is assumed.

2. Identify local soil properties that limit use. These were, for Leon County, water table depth, permeability, slope, and flood hazard.

3. Determine ranges of each soil property or conditions that determine the degree of limitation and that help identify the kind or specifications of corrective measures (CM). An example is given for water table depth in Table 3.

4. For each soil condition, determine the limitations that continue after feasible corrective measures are

TABLE 3: Worksheet for preparing corrective measures in septic tank absorption fields, Leon County, Florida (modified after McCormack and Johnson, 1982)

Soil Evaluation Factor	Soil Conditions (ft)	Degree of Limitation	Effects on Use	Corrective Measures: Kind	Corrective Measures: Cost ($)	Corrective Measures: Index	Continuing limitations: Kind	Continuing limitations: Cost ($)	Continuing limitations: Index
Water table depth	6	Slight	None						
	3-6	Moderate	Possible contamination of groundwater	Additional labour because of difficulty in installing tank	50	1	Possible contamination of groundwater	100	3
	1 1/2-3	Severe	Surfacing of effluent	Add 2 ft of fill ($89 yd^3$@$6/$yd^3$)	534	13	Possible contamination of groundwater, need for occasional pumping	150	4
	0-1 1/2	Severe	Nonfunctioning system	Add 4ft of fill ($178 yd^3$@$6/$yd^3$) lift pump uphill perimeter drain	1 070 800 800	27 20 20	Possible contamination of groundwater, need for occasional pumping	250	6
	+2-0	Severe	Nonfunctioning system	Add 7ft of fill (311 yd^3@$5/$yd^3$)	1 870	47	Possible contamination of groundwater, need for occasional pumping	250	6

installed (CL). Intensive discussions dealt with the locations of failure and successes of local installations and the soils on which they occurred.

5. Determine the costs of each corrective measure (CM) and of the continuing limitations (CL). These were assessed by the local experts. These were often costs of maintenance, but in other cases represented the degree of aggravation or discomfort to the homeowners or community.

6. Devise an index system through which the values of CM and CL are placed on a uniform scale compatible with the value of the performance index (P). For simplification, P was set at 100, and CM and CL were determined by multiplying the costs by 0.025.

7. Determine classes of soil and site conditions of each soil mapping unit for each evaluation factor.

8. Determine the effect of each soil and site condition on the function of the system, assuming standard installaion. For example, Table 4 indicates that contamination of the water table and difficulty of installation are possible effects of a high seasonal water table.

9. Identify feasible corrective measures (CM) continuing limitations (CL) and costs for each limiting soil or site condition of each mapping unit. Possible combined effects of the limiting factors are also considered.

10. Apply indexes to each CM and CL for each soil according to the guidelines established in Step 6.

TABLE 4: Worksheet for preparing soil potential rating for septic tank filter fields on Norfolk loamy fine sand, 2 to 5 percent slopes, Leon County, Florida (modified after McCormack and Johnson, 1981).

Evaluation Factor	Soil and site conditions	Degree of Limitation	Effects of Use	Corrective Measures: Kind	Corrective Measures: Index	Continuing limitations: Kind	Continuing limitations: Index
Flooding	None	Slight	None				
Water Table depth	4-6ft	Moderate	Possible contamination of ground water	Additional labour because of difficulty installing tank	1	Possible contamination of ground water	3
Permeability	0.6-2.0 in/hr.	Moderate	Failure of system	Enlarge field to 570ft^2	5	None	
Slope	2-5 percent	Slight	Surfacing of effluent on lower slopes	Design and install system to distribute effluent in drain	5	Surfacing of effluent on lower slopes	1
Index values					11		4

100 (performance standard index) - 11 (measure cost index) - 4 (continuing limitation cost index) = 85 (soil potential index)

11. Determine SPI for each soil. The Norfolk soil in Table 4 has an SPI of 85.

12. Establish class limits for soil potential as follows:

	Class Limits
Very high potential	95-100
High potential	84-94
Medium potential	64-83
Low potential	45-63
Very low potential	0-44

McCormack and Johnson (1982) observe that this approach permits extensive local practical knowledge about soils to be correlated accurately with the soil survey. At the same time, the soil scientist learns how to make soil surveys more useful.

Fritton et al. (1982) address the problem of delivering the information available about a site to the decision-maker at the local level with little or no computer knowlege. An interactive site evaluation model was developed that is centred around two categories of information - information required to satisfy legal regulations and information required for water flow models. The model was developed at Pennsylvania State University, and reflects the regulations of the Pennsylvania Department of Environmental Resources.

The user is first asked a series of questions to check

that the legal distance requirements - from water bodies and supplies, property lines, buildings, and so on - are met. If any of these regulations are violated, a failure message is sent, and the model stops. If not, the program continues.

Next, a series of questions is asked in order to define the depth to any limiting zones (such as a seasonal high water table, or highly fractured rock). These are important to the regulations, and also ultimately set the boundary conditions for the numerical water flow model. Other information is then requested of the user, including percolation rates, the depths at which permeability changes in the profile, type of residence and number of bedrooms, and the maximum width and length of the proposed absorption field.

The Pennsylvania regulations require a profile description for the site. The next series of questions is aimed at determining what soil is found at the site from the profile description and from the soil mapping unit the site is located in, as taken from a Soil Survey Report for the county. This was not always possible, as some soils were not separated from others in the same county, forcing the user to choose between profile descriptions. Soil variability and inclusions also can create difficulty.

Water flow models require that the hydraulic conductivity of the modelled layers be known. Hydraulic conductivity is empirically derived from the percolation

rate in the program; another source is the soil data base.

The user is given a choice of any or all of five system types (standard trench, seepage bed, elevated sand mound, subsurface sand filter, or intermittent sand filter). The program first checks for non-compliance with site characteristic or lot area restrictions. If the system passes, then the input data for the water flow model is generated, either by the user or the computer. The maximum trench depth, and width and number of trenches or bed are calculated. Boundary conditions are set for the model. In all cases, the systems are simulated in two dimensions for a cross-section through the absorption system. Clogging in the trench bottom and sides can be simulated by specifying a negative pressure or tension; with no clogging, there will be a zero-pressure head at the bottom and sides of the trenches.

The simulation model determines the recommended absorption area based on a constant field width, and returns to the main program the recommended length of the absorption area. The main program takes the output from the water flow models and determines the required absorption area. If the models predict that flow out from the trenches is not adequate, a warning message will alert the user that the system is legal, but predicted to fail. For the systems that meet the flow requirements, the predicted absorption area is compared to the legal requirements. If all checks are satisfied, a message to that effect is printed for each acceptable system.

Model verification and validation indicate that the water flow model used tends to over predict flow. The discrepancy is in the order of $^{+}$33%, and the authors felt that since the input data at a given site was subject to larger errors, this accuracy could be considered acceptable until something better appears. A more sophisticated clogging feature is needed as at present the user is forced to choose a boundary potential value for the trench boundaries. This is especially important as clogging is often the limiting factor for flow.

This approach might be of considerable value to inspectors and to contractors involved in the design of systems. The interactive language would make it easy to learn, and a linkage in the system between the regulatory agencies and the users (ie. contractors) would probably speed the permit-granting procedure.

Access to the Canadian Soil Information System (CaNSIS) files could, with adaptations to the program, allow the soil at a particular site to be correlated with a taxonomic series, with all its associated properties. CaNSIS is a national soil data system established by the Canada Soil Survey Committee, using a computerized system of file management. The information stored in CaNSIS includes descriptive and observational data collected in the field, frequently augmented by laboratory analysis (Canadian Soil Survey Committee, 1978a). A draw-back is that few contractors have the background to describe a soil profile.

At the same time, soil scientists in Canada are not employed by county or municipal governments as commonly as they are in the U.S. to classify and map soils. If few people are available to provide the necessary input to the model, then the model can only be of limited use. The discrepancy between estimated and actual water flow amounts is another serious flaw to the model.

In this discussion of different attempts to evaluate potential sites for on-site sewage disposal systems, a steady progression has been observed. First, the properties of soil and landscape important to effluent disposal were identified. Then, evaluation schemes attempted to determine simply whether or not a system could provide successful sewage treatment. Later evaluations identified the potential causes of failure and seriousness or probability of the failure. Still later, the measures necessary to overcome these problem situations were defined. Then other systems tried to assess the relative costs of different systems built in different situations. Finally, interactive computer models are being perfected whereby the user or builder can custom-design a system to meet the prevailing soil-landscape-water use conditions.

III MOISTURE MOVEMENT PROPERTIES OF EDMONTON AREA SOILS

1. INTRODUCTION

Surface infiltration rates and percolation rates were determined at twenty-five sites in the Edmonton area. The sites were chosen to represent a variety of soil parent materials and soil development. The main objectives were:

1. To determine the range of infiltration and percolation rates in the area;
2. To relate these values to soil characteristics and to the results of the 1978 survey of sewage disposal system performance;
3. To determine correlations between the measuring techniques.

2. METHODS

The sites were chosen using the Soil Survey of the Edmonton Sheet (Bowser et al., 1962) as a guide and then checking for locations where access could be gained, with the desired combinations of soil and parent material. The following kinds of soils were tested:

1. Beaverhills - an Orthic Black Chernozemic soil on medium textured till.
2. Angus Ridge - an Eluviated Black Chernozemic soil

on medium-textured till.

3. Cooking Lake - a Gray Luvisolic soil on medium-textured till.

4. Malmo - an Eluviated Black Chernozemic soil on fine-textured lacustrine material.

5. Navarre - an Orthic Black Chernozemic soil on fine-textured lacustrine material.

6. Maywood - a Gray Luvisolic soil on fine-textured lacustrine material.

7. Winterburn - an Orthic Dark Gray Chernozemic soil on medium to moderately coarse textured pitted deltaic material.

8. Ferintosh - an Orthic Black Chernozemic soil on coarse-textured glacio-fluvial material.

9. Kavanagh - a Black Solonetzic soil developed on Edmonton formation bedrock.

10. Heart - a complex of Brunisolic soils on alluvial-eolian material.

11. Leith - a Dark Gray Luvisolic soil on alluvial-eolian material.

At each site infiltration rates were determined by double-ring infiltrometer (Bouwer, 1961) using a constant head measuring cylinder of local design[1]. The design and operating instructions for this measuring cylinder are included in Appendix 1.

1 J. Tajek, personal communication.

Percolation tests were conducted according to the standards outlined by the Alberta Department of Labour (1977). This entails augering a 20 cm diameter hole to a depth of 100 cm, and monitoring the rate of water drop at the 50 cm level until a constant rate was obtained. These field determinations were done in triplicate. As well, three semi-disturbed cores were removed from each of a) the surface 10 cm of mineral soil, b) the 50-60 cm level, and c) the C horizon, at about 90 cm. Bulk density was determined on cores from all sites. Some cores were submitted to the Alberta Agriculture, Irrigation Division laboratory at Lethbridge for determination of constant head hydraulic conductivity. A detailed soil description was made at each site. Figure 2 shows the locations of the test sites.

3. RESULTS AND DISCUSSION

The results of the infiltration and percolation tests for the twenty-five sites (Table 5) indicate a wide range of values.

Final infiltration rates extended from no observable infiltration (N.I. in Table 5) to as high as 0.6 min/cm. The range for the percolation tests was about the same.

Neither test yielded consistently higher results than the other for all soils and parent materials but there was a pattern to the relative values of the two tests. The percolation rates were consistently twice as fast as the

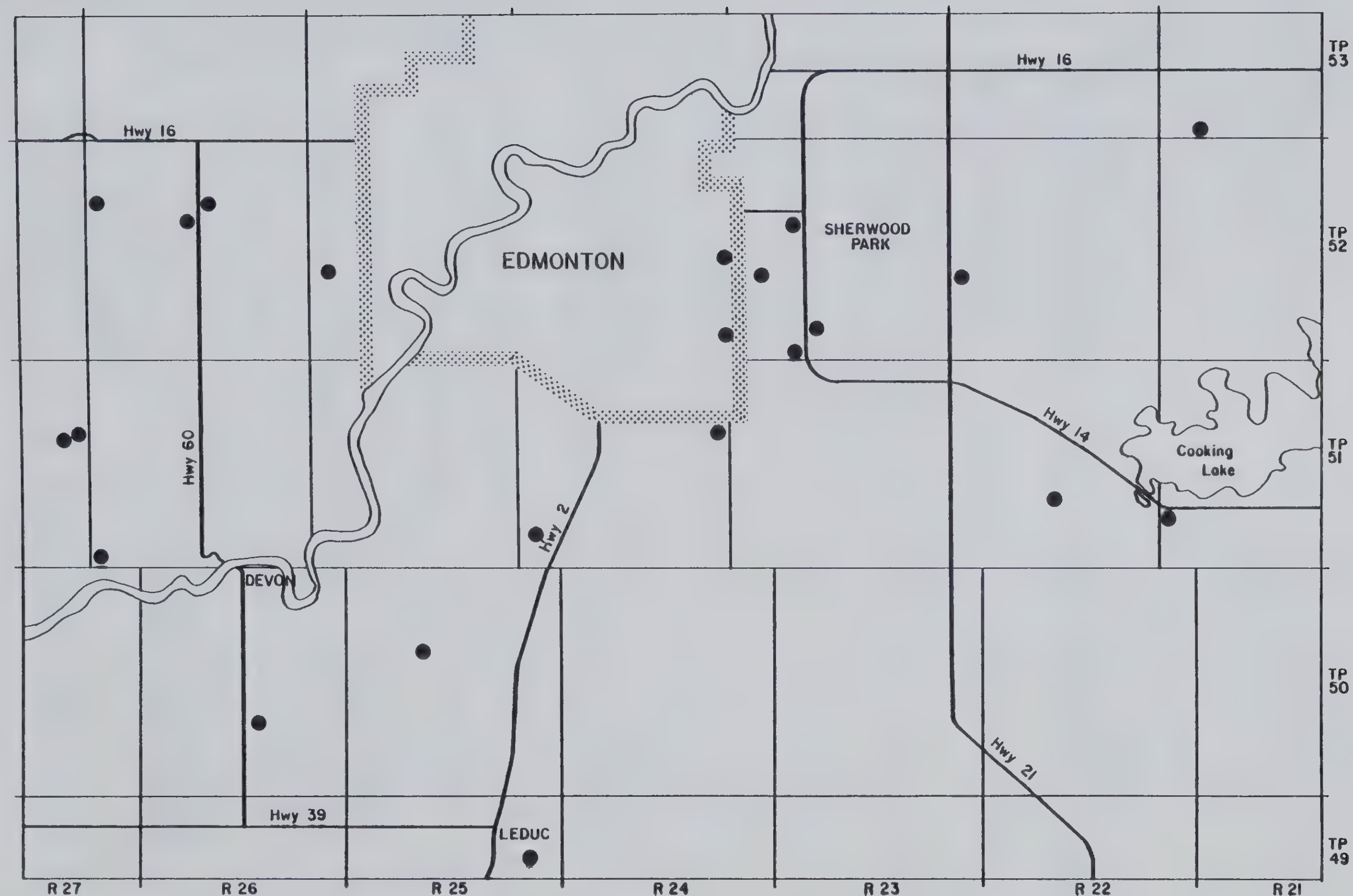


FIGURE 2. LOCATION OF INFILTRATION AND PERCOLATION TEST SITES

Table 5. Test site soils, moisture movement properties and bulk densities.

Soil Sub-Group	Soil Series	Parent Geological Material	Family Particle Size	Infiltration Rates (min/cm) (h_1=5cm)				Percolation Rates (min/cm)				Bulk Density (g/cm^3)			(Lethbridge)[2] Bulk Density (g/cm^3)			Hydraulic Conductivities (cm/sec)		
				$\bar{X}_1$	$\bar{X}_2$	$\bar{X}_3$	$\bar{X}_{all}$	X1	X2	X3	Xall	Level 1	Level 2	Level 3	Level 1	Level 2	Level 3	Level 1	Level 2	Level 3
O.BL.	Beaverhills	Till	loam	2.5	5.5	6.0	4.7	7.0	5.0	5.0	4.0	0.83	1.17	1.47	1.2	1.3	1.5	--	--	4.4×10^{-6}
O.BL.	Beaverhills	Till		7.2	3.0	10.8	7.0	2.5	2.6	1.1	2.1	1.44*	1.58*	1.68*	1.4	1.6	1.6	--	5.6×10^{-6}	4.7×10^{-6}
E.BL.	Angus Ridge	Till	loam	0.90	1.9	2.0	1.6	3.6	1.3	4.2	3.0	0.90	1.45	1.63	--	1.6	1.6	--	2.8×10^{-6}	3.3×10^{-6}
E.BL.	Angus Ridge	Till		1.6	1.0	1.4	1.3	3.9	3.4	3.5	3.6	0.99	1.50	1.57	--	--	--	--	--	--
E.BL.	Angus Ridge	Till		3.7	135	3.5	3.6	20.0	5.0	5.9	10.3	1.32	1.56	1.57	--	--	--	--	--	--
O.GL.	Cooking Lake	Till	loam	132	17.9	172	107	35.0	50.0	38.3	41.1	1.41*	1.30*	1.40*	--	--	--	--	--	--
O.GL.	Cooking Lake	Till		150	NI[1]	186	>168	250	250 0	250	250	1.6[2]	1.7[2]	1.8[2]	--	--	--	--	--	--
O.GL.	Cooking Lake	Till		2.2	2.0	5.8	3.3	NI	60.0	15.0	>38	1.23	1.50	1.54	--	--	--	--	--	--
E.BL.	Malmo	Lacustrine	silty loam	7.4	9.0	6.0	7.5	105	78.0	15.0	66.0	1.12	1.28	1.10	--	--	--	--	--	--
E.BL.	Malmo	Lacustrine		60.0	184	213	152	11.1	10.9	6.5	9.5	1.02*	1.53*	1.57*	--	--	--	--	--	--
O.BL.	Navarre	Lacustrine	silty loam	16.8	13.9	11.3	14.0	3.7	3.8	3.7	3.7	1.09	1.28	1.16	--	--	--	--	--	--
O.BL.	Navarre	Lacustrine		NI	NI	NI	-	4.4	4.9	3.4	4.2	1.12	1.24	--	--	--	--	--	--	--
O.GL.	Maywood	Lacustrine	clay loam	112	NI	17.3	>44.6	49.0	25.3	49.7	41.3	1.24	1.32	1.41	1.26	1.36	1.39	1.3×10^{-4}	2.8×10^{-6}	1.7×10^{-6}
E.BL.	Winterburn	Pitted Deltaic	loam	13.4	32.3	8.9	18.2	4.4	3.9	4.5	4.3	1.19*	1.44*	1.38*	1.21	1.41	1.28	2.2×10^{-3}	2.3×10^{-4}	3.9×10^{-4}
E.BL.	Winterburn	Pitted Deltaic		1.4	0.6	1.6	1.2	1.9	1.1	1.0	1.3	1.00	1.26	1.26	--	--	--	--	--	--
HU.LG.		Lacustrine		6.9	0.6	1.1	2.9	0.5	5.4	5.3	3.7	0.66	1.46	1.34	0.72	1.39	1.38	2.1×10^{-3}	8.8×10^{-5}	1.4×10^{-4}
D.GL.	Leith	Alluvial-Eolian	sandy loam	4.2	7.3	3.7	5.1	1.7	2.0	1.7	1.8	1.38*	1.68*	1.41*	--	--	--	--	--	--
D.GL.	Leith	Alluvial-Eolian		6.4	39.1	.76	2.4	1.8	2.0	2.0	1.9	1.42	1.48	1.41	1.60	1.54	1.56	2.0×10^{-4}	5.0×10^{-4}	3.6×10^{-3}
D.GL.	Leith	Alluvial-Eolian		1.5	3.8	1.1	2.1	0.5	0.9	0.9	0.8	1.40	1.34	1.32	1.58	1.49	1.43	1.0×10^{-3}	2.4×10^{-3}	3.4×10^{-3}
FE.LG.		Alluvial-Eolian	sandy loam	5.1	3.8	4.4	4.4	2.0	1.8	1.5	1.8	1.41	1.43	1.43	1.54	1.57	1.56	1.2×10^{-3}	6.0×10^{-4}	6.0×10^{-4}
E.EU.	Heart	Alluvial-Eolian	loamy sand	1.8	1.0	2.3	1.7	0.7	1.3	0.7	0.9	1.44	1.33	1.42	1.44	1.44	1.44	1.8×10^{-3}	3.0×10^{-3}	3.0×10^{-3}
BL.SZ.	Kavanagh	Residual	loam	NI	NI	NI	-	NI	NI	NI	-	1.36*	1.46*	1.40*	--	--	--	--	--	--
BL.SZ.	Kavanagh	Residual		NI	NI	NI	-	NI	NI	NI	-	1.13	1.53	1.60	--	--	--	--	--	--
BL.SZ.	Kavanagh	Residual		NI	NI	60	>220	NI	NI	NI	-	1.20	1.41	1.46	--	--	--	--	--	--
O.BL.	Ferintosh	Outwash	sandy loam	2.1	4.0	5.2	3.8	0.9	0.8	0.5	0.7	1.60*	1.82*	1.78*	--	--	--	--	--	--

* Large Corer
1 No Infiltration
2 Determined at Alberta Agriculture lab, Lethbridge

value of the infiltration rates on the soils developed in medium-textured (fine loamy) alluvial-eolian material, whatever the soil sub-group. For lacustrine material, the percolation rate was less than the infiltration rate in four of five cases, and by considerably more than half in three out of five.

The infiltration rate tended to be greater than the percolation rate on well-structured fine loamy Eluviated Black Chernozemics in till (Angus Ridge series). These soils have experienced the downward movement of clays, with their accumulation in the Bt horizon, but also have deep organic-rich surface horizons. The Bt horizons of Angus Ridge soils are usually found within the 50-100 cm range. Hence, the percolation test measured flow into the Bt horizon while the infiltration test measured flow through the thick friable Ah horizon.

Within sites, readings were usually more consistent for the percolation test replicates than for the infiltration tests. There are several possible reasons for this. The replicates of the percolation tests were conducted in a very small area, with the three test holes no more than a metre apart. The infiltration tests required a larger surface area than the percolation tests, and because of disturbance to the surroundings as each replicate was run, these replicates were set farther apart than for the percolation tests. Thus soil variability was reduced to a minimum for the percolation tests.

Generally, there was good agreement between the two sets of bulk density data. Two coring tools were used to collect samples, one of 7.5 cm diameter and the other of 3.8 cm diameter. Those sites where the larger sampler was used are indicated in Table 5 by an asterisk. The larger corer was used for all the samples sent to Lethbridge. While an extensive calibration of the two samplers was not carried out, in some cases, both sizes of cores were removed. Usually, the larger produced slightly higher values. The density values determined at Lethbridge for the large cores appear to bear this out, especially for coarse loamy parent materials.

Bulk densities at the upper level (level one) are least for the Chernozemic soils, reflecting their granular structure and high organic matter content. The densities were greatest at the upper level for the Luvisolic soils. At greater depths a pattern existed that seemed to be related to parent material. The lowest levels of six of the eight soils developed in till had densities of from 1.5 to 1.6 g/cm^3, while most soils developed in lacustrine material had densities of 1.2 to 1.3 g/cm^3. These differences probably reflect particle size distribution. Fine-textured lacustrine material is associated with greater porosity, and hence lower density, than the slightly coarser till. The bulk density at the 50 cm level was usually intermediate between the upper and lower level values.

Soils with sandy parent materials (alluvial-eolian and

pitted deltaic) had hydraulic conductivities two to four orders of magnitude greater than those of the finer-textured soils on till or lacustrine materials at the lower two levels.

K_{sat} was about 10^{-3} or 10^{-4} cm/sec for the alluvial-eolian material, and 10^{-5} to 10^{-6} cm/sec for till and lacustrine materials.

Within sites, the surface level had the most rapid hydraulic conductivity. It was usually slowest at the 50 cm level, which most often was within the B horizon. The BC or C horizon K_{sat} was often slightly faster than that at 50 cm but in any case, the two were quite comparable.

Table 6 lists the average infiltration rates for each of the soil series examined, arranged in order of decreasing infiltration. For half of these soil series, less than six minutes were required for a centimeter of water to enter the soil. For the remaining five soil series, more than 27 minutes was required per centimetre. The soils with rapid infiltration were either Chernozemic soils with deep Ah horizons that had developed in till (Angus Ridge, Beaverhills series) or they were soils that had developed in coarsely textured fluvial or eolian materials (Leith, Winterburn and Ferintosh series). The slow group of soils had formed either in saline residual material (Kavanagh series) or fine-textured lacustrine material (Navarre and Maywood series). Orthic Gray Luvisols formed in till (Cooking Lake series), though, also had very slow

TABLE 6. Soil Series and Average Surface Infiltration Rates.

SOIL SERIES	NO. OF SITES	PARENT MATERIAL	FAMILY PARTICLE SIZE	SOIL ORDER	INFILTRATION RATE (MIN/CM)	(CM/SEC)
Winterburn	2	Pitted Deltaic	Loam	Chernozemic	2.1	1.2×10^{-4}
Angus Ridge	3	Till	Loam	Chernozemic	2.2	1.3×10^{-4}
Leith	3	Alluvial-Eolian	Sandy Loam	Luvisolic	3.2	8.7×10^{-5}
Ferintosh	1	Glacial Outwash	Sandy Loam	Chernozemic	3.8	7.3×10^{-5}
Beaverhills	2	Till	Loam	Chernozemic	5.9	4.7×10^{-5}
Navarre	2	Lacustrine	Silty Loam	Chernozemic	27.9	9.9×10^{-6}
Maywood	1	Lacustrine	Silty Loam	Luvisolic	44.6	6.2×10^{-6}
Malmo	2	Lacustrine	Silty Loam	Chernozemic	80.0	3.5×10^{-6}
Cooking Lake	3	Till	Loam	Luvisolic	113.0	2.5×10^{-6}
Kavangh	3	Residual	Loam	Solonetzic	NI [1]	9.3×10^{-7}

1 No infiltration

infiltration rates in contrast to the rapid rates for the Chernozemic soils on till. The Navarre and Maywood series sites did not demonstrate nearly so great a difference in rates, despite the same kind of difference in horizonation on a common parent material. The very fine texture of the lacustrine material apparently overrode much of the effect of soil development differences.

The pattern of the percolation rates (Table 7) was the same as for the infiltration rates in that a wide gap existed between the "fast" and the "slow" soils. The relative ranking of the series has altered slightly, compared to the infiltration rate, but only one has moved between the "fast" and the "slow" groups. This was the Navarre series, grouped with the "slow" soils for infiltration, but with the "fast" soils for percolation.

Eluviation and illuviation processes appeared to be of importance, with Luvisolic soils consistently appearing further down in the table than the Chernozemic soils on the same parent material. The Cooking Lake series had the second lowest rate of all series examined, while the Beaverhills and Angus Ridge series, both Chernozemics, were among the fast group.

The probable cause was the translocation of clay within the soil profile, leading to the development of a dense clay enriched Bt horizon in the Luvisolic Cooking Lake soil.

The average values for infiltration and percolation have been converted to cm/sec, so that they can be compared

TABLE 7. Soil Series and Average Percolation Rates.

SOIL SERIES	NO. OF SITES	PARENT MATERIAL	FAMILY PARTICLE SIZE	SOIL ORDER	INFILTRATION RATE (MIN/CM)	INFILTRATION RATE (CM/SEC)
Ferintosh	1	Glacial Outwash	Sandy Loam	Chernozemic	0.7	4.0×10^{-4}
Leith	3	Alluvial-Eolian	Sandy Loam	Luvisolic	1.5	1.9×10^{-4}
Winterburn	2	Pitted Deltaic	Loam	Chernozemic	2.5	1.1×10^{-4}
Beaverhills	2	Till	Loam	Chernozemic	3.1	9.0×10^{-5}
Navarre	2	Lacustrine	Silty Loam	Chernozemic	4.0	6.9×10^{-5}
Angus Ridge	3	Till	Loam	Chernozemic	5.6	5.0×10^{-5}
Malmo	2	Lacustrine	Silty Loam	Chernozemic	38.0	7.3×10^{-6}
Maywood	1	Lacustrine	Silty Loam	Luvisolic	41.3	6.7×10^{-6}
Cooking Lake	3	Till	Loam	Luvisolic	146.0	1.9×10^{-6}
Kavanagh	3	Residual	Loam	Solonetzic	NI [1]	9.3×10^{-7}

1 No infiltration

to the saturated hydraulic conductivities. The orders of magnitudes for all three tests on the same series was usually the same. They were most similar where soil structure was minimal, such as in the Heart and Leith soils. These soils were also less susceptible to smearing and compaction, so that they should have been less affected by the coring and testing process than the finer-textured soils.

4. CONCLUSIONS

Soils at sites representative of several different soil series important in the Edmonton area were found to have varying abilities to accept and transmit water. This ability appeared to be related to the soil parent material and also to soil genetic development. Coarsely-textured, fluid-sorted material was associated with the highest rates of infiltration, percolation, and hydraulic conductivity. Lacustrine deposits and saline affected residual bedrock were associated with slow rates. Rapid rates of infiltration and high hydraulic conductivities were measured in thick, granular Ah horizons. Dense Bt or Bn horizons gave very slow rates.

Percolation tests yielded results that were more consistent within test sites than had been anticipated. The test was applied, though, using a rigidly controlled procedure. In the past, the major problem has been that this test will give significantly different results if the procedure is even slightly modified (Derr et al., 1969). The percolation test is probably best used to compare the relative performance of different soils. The test yields an uncontrolled average of the moisture properties within a soil individual and should be otherwise used with some caution (Derr et al., 1969).

Neither test gave consistently higher results than the other. However, the percolation test gave consistently more

rapid rates than the surface infiltration tests in coarsely textured materials. On fine-textured materials, though, percolation test results are slower than the infiltration test values.

In the 1978 survey on sewage disposal system performance (Gardiner, 1978), high rates of system failures were observed on several Luvisolic soils (Cooking Lake, Maywood soils), on Solonetzic soils (Kavanagh), and on some Eluviated Black Chernozemic soils (Angus Ridge, Malmo). In the water flow tests, except for the Angus Ridge series, these soils were in the slow group of infiltration and percolation rates. Although the causes of system failure were rarely explicit, these failures can be largely attributed to slow moisture flow properties combined with inadequately sized effluent absorption field.

IV DETAILED FIELD MAPPING AND SOIL INTERPRETATIONS FOR ON-SITE SEWAGE DISPOSAL

1. SITE DESCRIPTION

Introduction

The two acreage subdivisons that were studied were located within 25 km of the Edmonton city limits (Fig. 3). To the east of the city is the subdivision known as Springhill Park, in NW5-52-22-W4. The other subdivision was Meadowcrest Estates, southwest of Edmonton in the east half of sec 24-51-27-W4. Only the north-east quarter of sec 24 was examined.

The two will be referred to in the text simply as Springhill and Meadowcrest.

Meadowcrest is situated in an area of stabilized parabolic dunes interpersed with poorly-drained organic deposits. Application to subdivide Meadowcrest was made in 1978. Although approval was granted shortly after that, as of 1982 only four of the fourteen lots in the quarter had dwellings on them.

Half the lots are about 1.2 ha in area, while the rest range up to 6 ha. Much of the quarter section is poorly drained. There, larger lots were specified by the Alberta Department of Environment to ensure that well-drained building sites existed on each lot. A small farm occupies

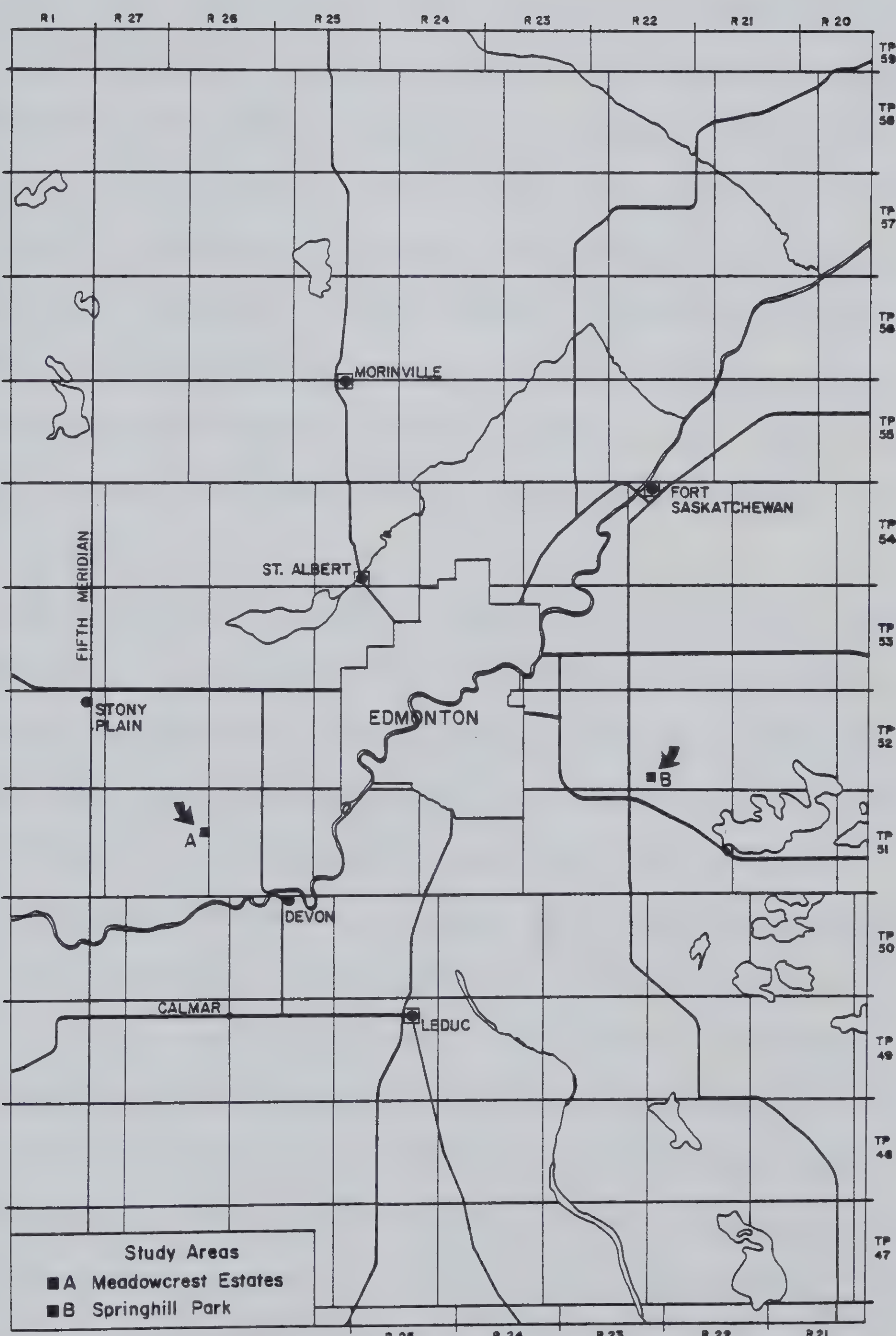


FIGURE 3. DETAILED FIELD MAPPING STUDY LOCATIONS

the northeast corner of the quarter section. This land is used for pasture.

Most of the well-drained areas are forested. However, the only sizeable dry area that is also gently sloping appears to have been cleared in the past and used as pasture. Presently, it has a cover of grasses and forbs. The forest seems to be moving back into this clearing, with many young trees and shrubs appearing near the forest edge. Some of the brush in the bogs in the northern part of the quarter has also been removed. This is not readily apparent on the ground, but the slash rows show up clearly on aerial photography.

Black and white aerial photography from the Alberta Government's 1949 series (AS 137 5307 91-92) showed a thinner forest cover than presently exists. The same areas were treed, but they had more open canopies. The bog area in the northern part had not yet been cleared.

Springhill Park is situated in a hummocky, dead-ice moraine landscape. Springhill has been subdivided for a few years longer than Meadowcrest. In the 1976 aerial photography used in mapping both areas, several of the structures now present at Springhill were just under constructon. The quarter-section is divided into 32 lots of approximately 1.2 ha in size; only two or three of these lots do not presently have houses on them. There is a park reserve of about twenty acres in the south-east corner, and a farmstead and pasture in the south-west corner.

Most of the quarter has been cleared of the native aspen forest. An examination of 1949 aerial photography (AS 136 5308 66-67) should the extent of the forest cover to be about the same as the present, with a few exceptions. An area of about two hectares has since been cleared in the northern part of the quarter. Other small areas, especially in moist locations, have experienced regeneration of the forest cover. The land appears to have been used mostly as pasture, although a level area on the east side shows signs of cultivation.

Surficial Geology

During the Pleistocene epoch, the region was covered at least twice by Laurentide ice sheets moving in a general southerly direction (Bowser et al., 1962). The last ice advance occurred 25,000 to 30,000 years ago. Melting of this glacier was essentially complete about 9,000 years ago, leaving the Edmonton area covered by surficial deposits of various kinds.

The Meadowcrest area is covered by a combination of eolian deposits and recent lake and slough deposits. This is part of a larger dune area extending from the west side of Township 51, Range 27 eastward to the North Saskatchewan River. Both longitudinal and parabolic (u-shaped, or blowout) dunes occur. Most of the dunes are less than 15 m in height.

According to an examination of the long axes of the dunes by Bayrock and Hughes (1962), the dunes were produced by north westerly (43° north of west) winds. The source material for the dunes is early North Saskatchewan River alluvium. This material was originally deposited by the North Saskatchewan River, flowing as a braided stream after the final draining of glacial Lake Edmonton. Later, one of the many channels was incised to form the present-day river valley (Bayrock and Hughes, 1962).

The lake and slough deposits in these sandy areas are mostly sands or organic materials. Marl deposits are also found.

The Meadowcrest area drains slowly. The elevation varies from about 700-710 m, and the fall of the land is to the east and south. No well-defined stream traverses the dune field. Drainage is almost directly into the North Saskatchewan or into an unnamed stream entering the North Saskatchewan in Sec 31 Tp 50, R 20.

The Springhill area is located in a hummocky dead-ice moraine, known as the Beaver Hills or the Cooking Lake Moraine. The till in this hummocky moraine is thick, generally from 12 to 45 m in depth, and may contain lenses of gravel, sand, and silt.

The main topographic features of the hummocky dead-ice moraine in the study area are knobs, kettles, prairie mounds, and stream trenches (Bayrock, 1973, in McPherson and Kathol, 1973).

Knobs are hills and hillocks circular to oval in plan outline, composed almost entirely of till. They range in size up to several hundred meters in diameter. They are most often about 5 m in height, but range from less than a metre to 15 m high.

Kettles are small, closed depressions produced by the melting of residual glacial ice that was completely or partially buried in the glacial drift. Knobs and kettles are the most common features of the dead-ice moraine in the area (Bayrock and Hughes, 1962). Prairie mounds resemble knobs, but have a small depression in the centre that often gives them the appearance of giant doughnuts.

A large glacial meltwater channel or stream trench is located along the southern edge of Springhill Park. This is part of a meltwater channel system extending from Cooking Lake to the hamlet of Bretona, a distance of nearly 20 km. In the Springhill area, this channel is about 300 m wide and 15-20 m deep. Typically, such channels are filled with a mixture of till and fluvial material and contain many ponds and lakes.

Tills of the Edmonton area consist mostly of local bedrock materials, with significant amounts of igneous and metamorphic bedrock material derived from the Canadian Shield to the northeast. The tills also contain Devonian carbonate rocks from outcrops along the margin of the Canadian Shield. Thus, although the local bedrock

formations tend to be low in calcium carbonate, the tills are calcareous because of the presence of Devonian limestones. Montmorillonite forms between 10 and 20% of the total clays (Bayrock, 1972).

A soil survey in Elk Island National Park (Crown, 1977) some 35 km northeast of the study area indicated the following features. Within 125 cm of the surface, colour ranged from yellowish brown to dark brown. Texture shifted from silt loam to loam and clay loam, while calcium carbonate equivalents changed from 2 to 10%. These variations occurred over distances of as little as 2 to 4 m.

At Springhill, the parent material textures were sandy clay loam to clay loam, but at the majority of inspections were silty clay loams. The C horizon colours are most often dark yellowish brown for the well-drained areas. Colour and texture are not quite so variable as for the Elk Island soils.

Climate

The closest meteorological recording station for both study sites is located at the Edmonton International Airport. Strictly speaking, the situation of the International Airport is not the same as either Springhill or Meadowcrest, being in an open, level agricultural area rather than one that is more hilly and forested. Springhill is higher by about 35 m, while Meadowcrest is at nearly the same elevation as the airport. Despite these differences,

the same regional trends of climate should apply to all three locations.

The present climate can be classified as continental with warm summers and cold winters (Brocke, 1977). January is the coldest month, with a mean temperature of -17°C, while July is the warmest month with a mean daily temperature of 16°C. On average, the frost free period is 100 days.

Total precipitation for the Edmonton area ranges from 300 to 640 mm, averaging 472 mm. The majority (70%) falls as rain between May and September, during the growing season. June and July each receive more than 80 mm of rain, and are the wettest months of the year. The snowfall averages 137 cm, and ranges between 76 to 230 cm. Most snow falls between December and March.

Precipitation events are usually gentle. Rainfall rarely exceed 130 mm per day, or snowfall, 38 cm.

Vegetation

According to Rowe (1972), Springhill Park is found within an outline of the Mixedwood Section of the Boreal Forest Region. On well-drained uplands, the characteristic association is a mixture in varying proportions of trembling aspen and balsam poplar, along with white and Alaska birch, white spruce and balsam fir. The last two species are especially prominent on old, undisturbed sites.

The forest cover at Springhill, where it exists, fits

Rowe's description well. It is mostly trembling aspen, with some balsam poplar and a few scattered spruce. The non-forested areas support mostly domestic grasses and various small shrubs and forbs.

The Meadowcrest study area is placed by Rowe (1972) in the Aspen Grove Section of the Boreal Forest. This is part of the forest-grassland transition, and has only trembling aspen abundant in the natural stands. Balsam poplar should be found in the moist lowlands. In the Meadowcrest area, though, the dunes are covered by jack pine, with aspen and balsam poplar farther down the slopes. Larch and black spruce border the bogs. Thus, the forest cover would appear to have greater affinities with the Boreal Mixedwood. In fact, Strong and Leggat (1981) place this area with their Boreal Mixedwood Ecoregion. This is defined to be essentially the same as Rowe's (1972) Boreal Mixedwood.

More detailed vegetation descriptions are included in the descriptions of the mapping units.

Previous Soils Studies

Both Meadowcrest and Springhill were included in the 1962 Soil Survey of the Edmonton Map Sheet (83H) (Bowser et al., 1962). The published map scale of this survey is 1:126,720.

The Meadowcrest area is partly included in a delineation of an organic map unit, with soils developed on undifferentiated sedge and moss peats. The rest is included

in a unit consisting of soils developed in alluvial-eolian material. Approximately 60% of the area is estimated to have Orthic Gray Luvisols (Culp series, loamy sand texture), while 20% should have Dark Gray Luvisols (Leith series, loamy sand texture). The remaining 20% consists of undifferentiated organic soils. The Meadowcrest study area has not since been remapped.

The Springhill area was included within an area of soil formed on "glacial till of Edmonton formation origin" (Bowser et al., 1962). The subdivision is found within a delineation which is estimated to consist 70% of Orthic Gray Luvisols (Cooking Lake series, loam texture), 10% of Dark Gray Luvisols (Uncas series, loam texture) and 20% of sloughs too small to show on the map.

The Springhill site was remapped by Menon (1971) at a scale of 1:15,840, as part of a study on the distribution of soils in central Strathcona County.

The soils of the subdivision were classed mostly as Orthic Gray Luvisols with loamy surface textures, and slopes of 2-5% and 9-15%. Areas of Terric Humisols also occurred in sloughs and closed depressions. Orthic Humic Gleysols developed in lacustrine material were mapped in the eastern third of the subdivision.

2. METHODS

Mapping Procedure

The soils and landscapes at Meadowcrest Estates and Springhill Park, were mapped at a scale of 1:5,000. The concepts for the mapping units were based on different combinations of soil parent material, the development of the dominant and significant soils, and internal drainage. The units were further subdivided on the basis of the dominant slope and surface expression. The vegetation dominant in each unit was also documented, but was not used to separate units.

The legends are of a controlled form; that is, each unique combination of soil and landscape is listed in the legend. The extended description included in the text groups the units according to parent material, drainage, and dominant soil.

Base maps for the subdivisions were 1:5,000 panchromatic photos enlarged from a 1:20,000 series flown in 1976. The Springhill base maps were derived from AS1546 frames 90 and 91. The Meadowcrest base maps were derived from AS 1546, frames 15 and 16.

A series of transects were run across each subdivision to gain a preliminary understanding of the soil and landscape patterns. The interval between observations along each transect was 15 m. This distance represents half of

the distance across a highly-contrasting, minimum-sized delineation that might be expected to be shown on a map of this scale (Arnold, 1979).

At each observation site, the sequence of soil horizons, their thickness, Munsell color notation, presence or absence of mottles and of free carbonates, field texture, structure, and consistence as specified by the Canada Soil Survey Subcommittee (1978a) were assessed. The slope class, slope position, aspect, drainage, surface expression, and parent material were also recorded. A grid system was applied to each subdivision and the site locations were recorded with reference to the grid. The grid spacings were 2.5 cm on the base map, further subdivided into tenths.

At Springhill, four traverses were run initially, while three were run at Meadowcrest. After assessing the information gathered in the traverses, preliminary legends were developed and delineations were drawn. Returning to the subdivisions, the tentative boundaries and the composition of the map units were checked by running additional transects. Any necessary changes in the boundary positions were made, and the unit definitions and legend were modified where required. Some further field checking was carried out during the summer of 1981.

Once the final field mapping was completed, representative sites were selected for the dominant soil in each map unit. At each, a complete soil description was made, and samples for each horizon were retrieved.

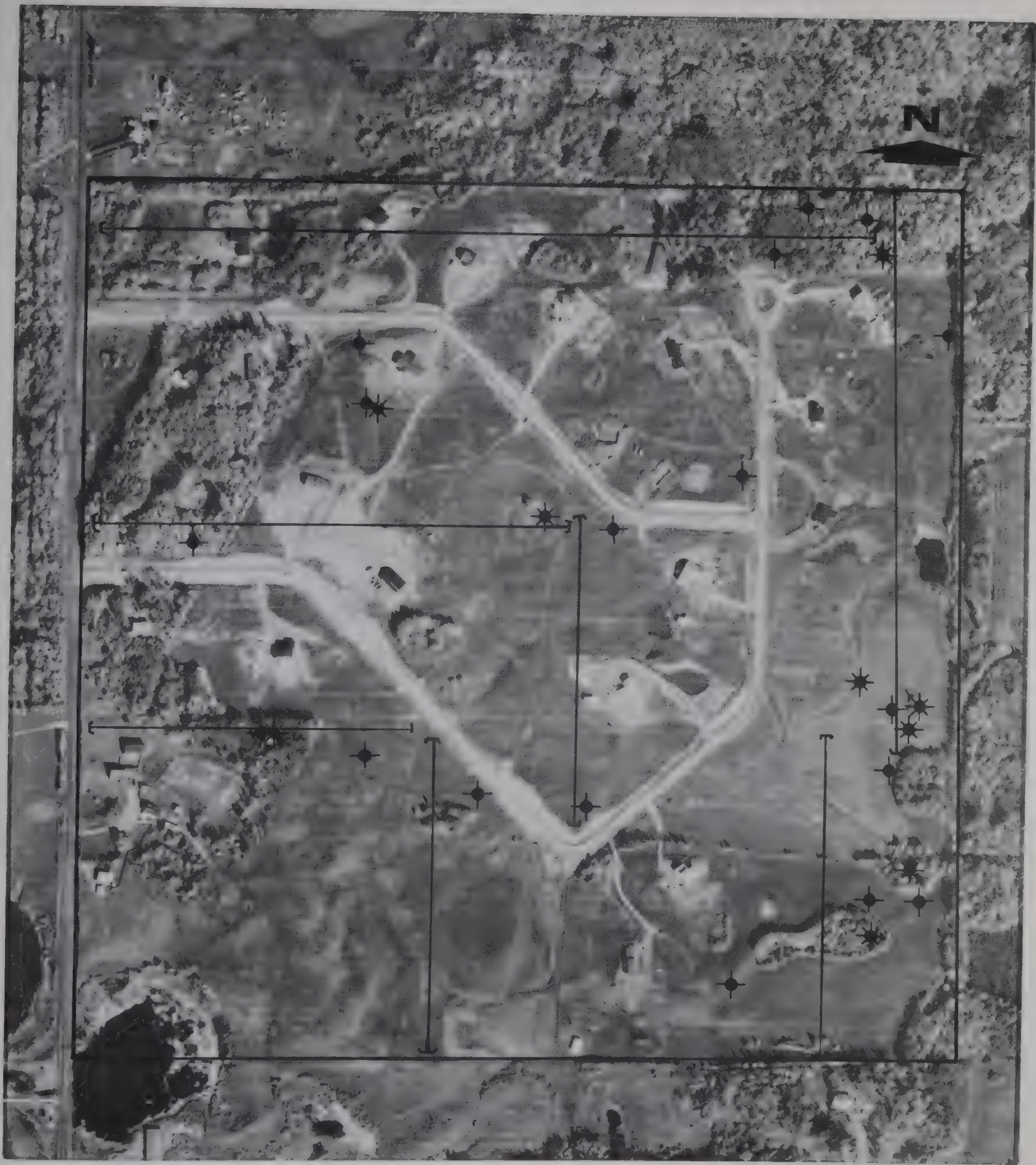
Laboratory analysis included particle size distribution by the hydrometer method (McKeague, 1978), coarse fragments (greater than 2 mm) by sieving, pH in 0.01 M. $CaCl_2$ (Peech, 1965) and Atterberg limits as specified by the American Society for Testing and Materials and outlined by McKeague (1978). The latter were only determined for the Springhill samples as the sandy Meadowcrest soils were non-plastic. While not required in most evaluation systems, the Atterberg limits provide a good indication of the workability of a soil. This will affect construction and installation of systems, especially in fine-textured soils.

In order to better assess the suitability of the mapping units for on-site sewage disposal, the dominant soils in the well-drained map units were also tested for moisture properties. The poorly-drained soils were not so tested since their drainage conditions would require special construction procedures before such sites could be made suitable for effluent disposal.

The locations of the traverses, the soil characterization sites and the moisture property test sites are indicated in Figure 4, for Springhill, and Figure 5 for Meadowcrest.

Hydraulic Conductivity

1. Field Measurement: Hydraulic conductivity was measured in the field at a depth of 50 cm, the depth specified for the installation of the trench lines of a sanitary field.



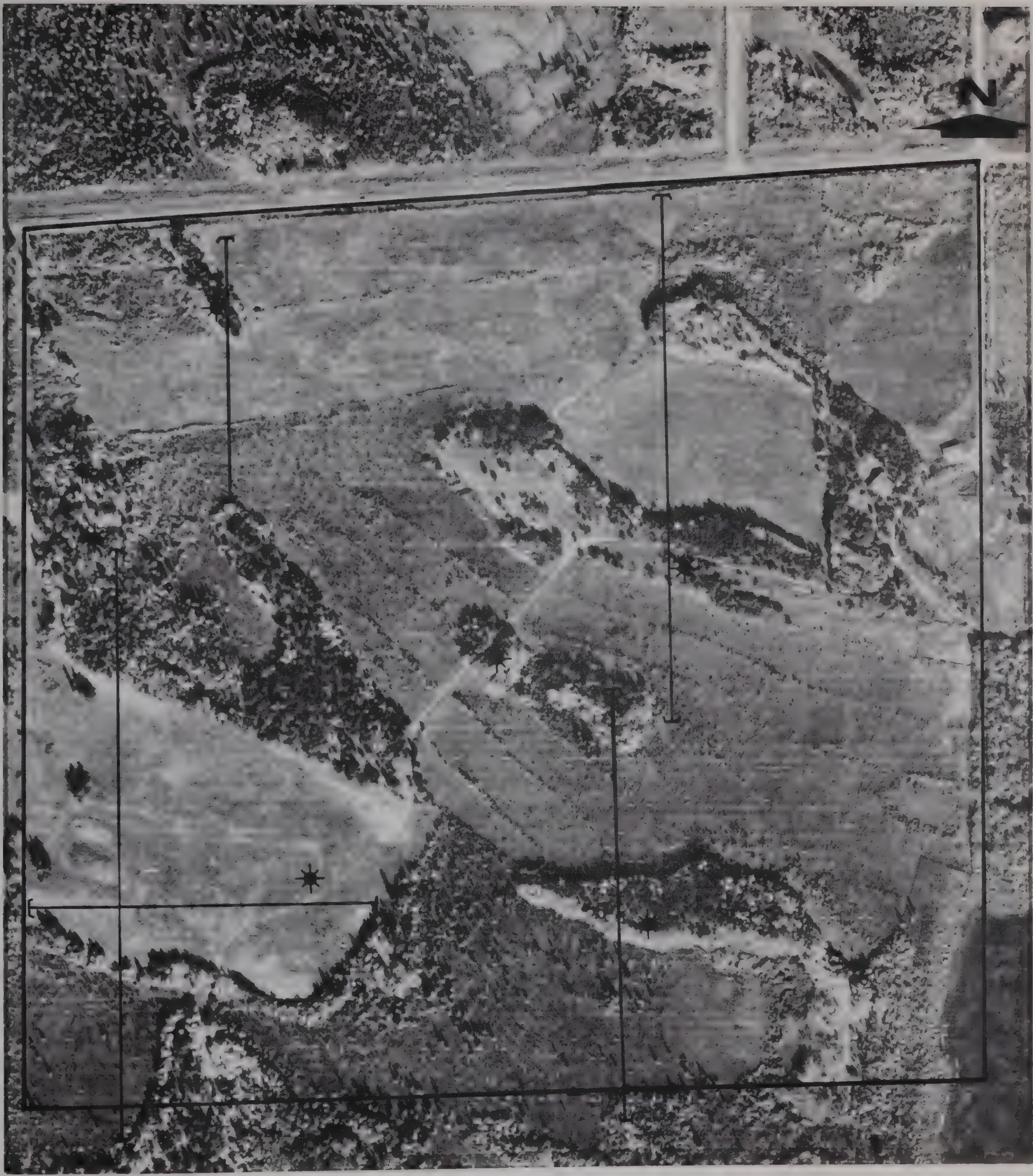
Scale 1:5 000

Transect

AEP Test Site

Sample Site

FIGURE 4. SPRINGHILL PARK TRANSECT, SAMPLE SITE, and A E P TEST SITES



Scale 1:5 000

Transect

Infiltration Test Site

Sample Site

FIGURE 5. MEADOWCREST ESTATES TRANSECT, SAMPLE SITE, and INFILTRATION TEST SITES

At Springhill, these hydraulic conductivity measurements were made using the air-entry permeameter (Topp and Binns, 1976). Appendix 1 includes a detailed plan of the instrument, along with the step-by-step procedure for its operation and calculation of K_{aep}.

At Meadowcrest, it proved impossible to use the air-entry permeameter (AEP). A wet summer and fall resulted in sandy soils that were never sufficiently dry to show a sharp change in the tensiometer reading as the wetting front passed. Therefore field measurements obtained using a double-ring infiltrometer and percolation tests (Alberta Labour, 1977) and described in Chapter III were subsituted.

2. Laboratory: The field measurements were supplemented by laboratory determinations of saturated hydraulic conductivity on 7.5 cm diameter semi-disturbed cores. These core determinations were especially important in the consideration of the Meadowcrest soils, because of the failure there of the AEP.

The cores were removed with a Uhland corer from the sampling sites at a depth of 50 cm, with three vertically oriented cores from each site. Where an AEP test had been conducted, the cores were taken from within the large permeameter ring after the test was completed. The cores were wrapped in plastic, stored in waxed cardboard containers and further sealed with masking tape.

Hydraulic conductivities for the soil cores from

Meadowcrest were measured using a constant-head permeameter as described in McKeague (1978). While suitable for the sandy Meadowcrest soils, this procedure was not appropriate for the finer-textured Springhill soils. Hydraulic conductivities for these soil cores were measured on a falling-head permeameter as outlined by Klute (1965).

After the hydraulic conductivity was determined, two of the cores from each site were oven-dried and weighed to determine the dry bulk density of the soil. The remaining core sample from each site was sliced and used to find the moisture retention properties at 0, 1, and 15 bar tensions. The pressure plate extraction technique for undisturbed soil cores, as outlined in McKeague (1978) was used.

The 0 bar moisture content assumes complete saturation, and values for it were obtained by further dividing the core samples after they were saturated and before they were placed in the pressure plate apparatus. Approximately half of each of the three subsamples was removed and saturation moisture content was determined. The average of the three subsamples from each core was then calculated.

When no more water was being extracted from the subsamples on the pressure plates, they were removed from the apparatus and their mass moisture contents were determined. These mass contents were converted to volumetric moisture contents by multiplying the mass basis values by the mean bulk density of the other two cores removed from the same site.

3. RESULTS OF FIELD MAPPING

Soils and Landscapes of Springhill Park (NW5-52-21-W4)

General: Dark Gray Luvisols were the most abundant soils, and occurred in well-drained hummocky, ridged and inclined terrain (Figure 6). They usually had a vegetation cover of grasses and forbs. Orthic Gray Luvisols were dominant in well-drained areas with a forest cover. In terrain with low relief and in depressions and hollows, a variety of Subgroups of the Gleysolic Great Group occurred. Organic soils (Terric Mesisols) were found in very poorly drained areas. Detailed descriptions of the soil-landscape relationships follow in the discussion of the mapping units. The main surficial material was till, with minor amounts of lacustrine and organic.

Mapping Units: Representative pedon descriptions and analytical data for each of the mapping units are found in Appendix 2

Unit 1: This unit is found in well-drained hummocky terrain that has for several years been cleared of forest cover. While the overall surface expression is hummocky, and while several polygons are so designated on the map, several inclined or ridged areas could be delineated within this

general pattern. The parent material for soil development is fine-textured till. The soils are dominantly Dark Gray Luvisols. In lower slope positions, Orthic Dark Gray Chernozems are common. Where slopes are greater than about 15%, though, these soils rarely occur. Slopes in this unit range from gently (6-9%) to strongly sloping (16-30%).

Soils of this unit usually have loamy or sandy loam surface (Ap) horizons. Often a remnant of an Ae horizon is present below the Ap, suggesting that these soils developed under a forest cover (Pettapiece, 1969). The Ap horizon is approximately 10 to 20 cm thick. The thinner Ap's tend to occur higher upslope, perhaps indicating that material has washed downslope. The B horizon texture is clay loam to clay. The Bt is well-developed in these soils, with strong blocky and prismatic structure, and extensive clay skins on ped faces. Free carbonates are often encountered within 100cm of the surface as coarse, white, strongly-effervescing concretions.

The Bt horizon may be strongly to extremely acid. The other horizons above the C horizon have slightly higher pH's than the Bt, while the C horizon itself is alkaline.

The vegetation typical of this unit is a mix of grasses and forbs representing abandoned cultivation. It includes brome grass, fescue, dandelion, strawberry, yarrow, alfalfa, vetch and other legumes. Scattered small shrubs, such as wild rose, are also present.

Unit 2: This unit occurs in undulating, moderately well-drained landscapes where lacustrine deposits form the soil parent material. These areas have been cleared of forest cover. Areas mapped as unit 2 can occupy wide troughs in the general hummocky landscape. They also occupy "plateaus" at the summits of the flat-topped prairie mounds. One delineation mapped as unit 2 is found within the major meltwater channel occupying the south-west corner of the quarter-section. Shallow, short-lived lakes may have occupied such depressions and troughs as glaciers melted and drainage of the glacial waters occurred, resulting in the deposition of a mantle of lacustrine material, probably over till.

The soils of this unit are dominantly Dark Gray Luvisols, with the significant occurrence of Orthic Dark Gray Chernozemics. A thin Ae horizon is usually present in both these soils, along with a thick Ap. Textures at the surface are silty, and clay content increases dramatically in the AB and Bt horizons to values often exceeding 50%. The profile is slightly acid to neutral above the Cca horizon. Free carbonates usually appear at about 75cm.

Slopes are very gentle (2-5%). The vegetation is very similar to that described for unit 1.

Unit 3: This map unit is associated with well-drained hummocky morainal terrain under a forest cover of aspen and

balsam poplar. However, as for unit 1 some larger inclined surfaces can be separated from the hummocky areas. Some small areas with undulating surface expression and very gentle slopes (2-5%) have been included in this unit, since they occupy such a small portion of the landscape and are not strongly contrasting in other characteristics. Otherwise, slopes for the unit are gentle (6-9%) to strongly sloping (15-30%).

The soils are dominantly Orthic Gray Luvisols. Some Gleyed Gray Luvisols are present in the undulating areas, and in some of the depressions in the hummocky areas. The soils typically have thick loam to sandy loam Ae horizons and well-developed clay loam to clay Bt horizons with strong compoind prismatic and blocky structure. Free carbonates were not always found within 100 cm of the surface. The profiles are strongly to extremely acid in the A and B horizons.

The forest canopy includes aspen and balsam poplar, while the thick understory includes shrubs such as hazel, high and low bush cranberry, dogwood, currant, raspberry and wild rose. Common forbs are sarsaparilla, anemone, bunchberry, various pyrola, strawberry, violet, bedstraw, and vetches.

Unit 4: This unit describes areas in level to undulating terrain with imperfect to poor drainage

conditions. The parent material is a lacustrine blanket over glacial till.

Most delineations of this unit are found in the eastern quarter of the subdivision in association with a large depressional area. The forest cover has been removed. This unit is similar to unit 2 in terms of parent material, but is more poorly drained.

The dominant soils are Humic Luvic Gleysols, and occassionally, Orthic Luvic Gleysols, where the surface mineral horizon are not thick enough and dark enough to meet the "Humic" requirements. In slightly elevated positions, Gleyed Dark Gray Chernozemics can be found.

The surface horizon is frequently an Ap horizon, although a thick O horizon may occur in uncultivated soils. Like the soils of Unit 2, the clay content below the A horizon increases dramatically with clay loam in the A and clay textures in the B and C. They are slightly acid to neutral above the calcareous C horizon. Carbonates are sometimes also present in the B horizon as fine white concretions.

Slopes are low, from nearly level (0.5-2.5%) to very gently sloping (2-5%). Vegetation includes brome, fescue, timothy, and such forbs as yarrow, dandelion, thistle, and vetch, along with such moisture-loving species as horsetail and blue-eyed grass.

Unit 5: This unit includes the small, poorly-drained depressions and hollows between hummocks and at the tops of prairie mounds. Many, but not all, of these areas have not been cleared of the original forest cover. The parent material for the soils in this unit appears to be medium-textured fluvial wash over till.

The soils found in this unit are Gleysols. Fera and Humic Luvic Gleysols, Fera and Orthic Gleysols, and Orthic and Fera Humic Gleysols all occur, with the Humic and the Luvic Gleysols being more common than the Gleysolic Great Group. Texture tends to be quite variable through the soil, ranging from sandy loam to clay or clay loam, but generally becoming finer with depth. The soils are prominently mottled, and in the case of the Fera subgroups, the mottles are almost continuous. The soils are mildly acid to neutral in reaction.

In the forested areas, the vegetation consists of a canopy of paper birch or balsam poplar, with an understory of willow and dogwood. The forest floor is covered by grasses, some sedge, currant, thistle, and wild rose. In the cleared areas, the vegetation cover includes brome, fescue, clover, dandelion, yarrow, and wild rose. Slopes are nearly level (0.5-2.5%).

Unit 6: This unit occurs in very poorly drained areas in undulating or depressional landscapes. Slopes are nearly

level (0.5-2.5%). The soils are Organic, of fen origin, with the organic material deposited over medium-textured lacustrine material. The dominant soils are Terric Mesisols and Terric Fibric Mesisols. On the boundaries of the unit and in slightly higher areas, the surface organic layer may thin out enough for the soil to be classified as peaty phases of Rego Gleysols or Rego Humic Gleysols. The organic material does not contain carbonates, nor does the mineral material immediately below it. On the Von Post scale of decompostion, the organic material was weakly to moderately decomposed with Von Post values between 3 and 5.

The vegetation consist of sedges, rushes, cow parsnip, and hydrophyllic grasses.

Unit 7: This unit consists of land disturbed in the construction of houses and outbuildings, driveways, and filled yards. Soil conditions are highly variable in that material may have been added or removed. Areas may have been drained, flooded, excavated, or compacted.

Unit 8: This unit consists of land disturbed in the construction of the main roadway and its ditches through the subdivision.

Unit 9: This unit consists of open standing water bodies, including lakes, ponds, and dugouts.

Correlation: Most of the soils encountered at Springhill can be correlated with soil series described in either the Soil Survey of the Edmonton map sheet (83H), (Bowser et al, 1962) or the Elk Island National Park Soil survey (Crown, 1977). The well-drained soils are the best differentiated, while the poorly-drained soils are not nearly so well separated, especially in the Edmonton report. Hence, the well-drained soils were found to closely correspond with named soil series, while the correspondence for the less well-drained soils was more tenuous.

The dominant soil of unit 1, the Dark Gray Luvisol developed in glacial till, closely corresponds with the description and general characteristics of the Uncas series. The Orthic Gray Luvisol, also developed in glacial till, which dominates unit 3, corresponds with the Cooking Lake series. The dominant soil in unit 2, the Dark Gray Luvisol developed in lacustrine material over till, does not correlate well with any series described in the Edmonton report, but it corresponds to the Tawayik series documented in the Elk Island National Park Soil Survey.

The Humic Luvic Gleysols that dominate unit 4 most closely correspond with the Prestville series, a very slowly

permeable Peaty Meadow (Humic Gleysol) soil developed in fine-textured material. The Luvic Gleysols of unit 5 coincide best with the Demay series, but the soils of this series have developed in morainal material. Parent materials for the unit 5 soils have a fluvial component. Organic soils (unit 6) were not differentiated in the Edmonton report.

The Bt horizons of the Orthic Gray and Dark Gray Luvisols (Cooking Lake series and Uncas series) do not differ greatly in their physical and chemical properties. According to Pettapiece (1969) such profiles are indicative of Bt formation beneath a forest cover. The dark-colored surface horizon would have developed subsequent to the removal of this forest cover.

The relative proportions of soils encountered in the subdivision do not correspond well with what is indicated in the Edmonton Soil Survey Report. There, seventy percent of the soils of the area were considered to be Orthic Gray Luvisols, whereas in this study, about seventy percent of the soils were Dark Gray Luvisols. Taking into account the scale differences, though, this cannot be considered a major discrepancy. The Menon study (1971), however, at a scale of approximately 1:16,000, also shows a dominance of Orthic Gray Luvisols, a finding that could not be confirmed at Springhill.

Soils and Landscapes of Meadowcrest Estates (NE24-57-27-W4)

General: The area was found to include several very well-drained u-shaped dunes rising above very poorly-drained fens (Figure 7). At one location, at the foot of a dune, soft bedrock was found within two metres of the surface. Presumably, water has ponded above this relatively impermeable material.

Most of the well-drained dune areas support mixed stands of jack pine, spruce, aspen and balsam poplar. The soils occuring under these conditions were classified as being dominantly Eluviated Eutric Brunisols, with some Orthic Eutric Brunisols.

Along the edges of the dunes, transitional areas exist that are intergrades between the well-drained dunes and the poorly-drained fens. The soils change in a very short distance from Gleyed Eutric Brunisols to Orthic Gleysols and Orthic Humic Gleysols with thick surface organic horizons. These peaty caps thicken as drainage becomes poorer, until sufficiently deep to allow classification of these soils in the Organic order.

A relatively level, well-drained sector of the subdivision has been clear of forest cover for at least thirty years (according to the 1949 aerial photograhy) and was evidently planted to forage crops. Presently the forest seems to be moving slowly back, with the occassional pine and spruce appearing along with more commonly shrubs such as

Saskatoon berry, wild rose and snowberry. Soils here are mostly Orthic Eutric Brunisols, with some Orthic Melanic Brunisols where the surface horizon is sufficiently dark.

In the wetlands, the soils were classified as various subgroups of the Fibrisol Great Group. The peat consisted of mostly fen material, which is usually associated with Mesisols. The botanic origin of most of the material could easily be determined, though, and application of the Von Post scale of decomposition placed most of the materials at the more decomposed end of the Fibrisols. Mesic and humic layers were occasionally noted though. Typic, Terric and Cumulo Fibrisols were identified. The mineral material in the Terric and Cumulo Fibrisols was aeolian in origin. There are suggestions of ribbing to the fens in the southern and eastern margins of the study area.

Mapping Units: Detailed soil descriptions and analytical data are included in Appendix 3. The units used in mapping Springhill and Meadowcrest are not to be correlated, even where the same numbers are used.

Unit 1: This unit includes very poorly drained areas with soils developed in organic deposits. The organic material is mostly of fen origin. On the Von Post scale of decomposition, the materials are generally between three and

five, or very weakly to moderately decomposed. There are, though, some layers where the material is very weakly decomposed (Von Post of 2), while other layers are strongly decomposed (Von Post of 6 to 7).

At the subgroup level, the dominant soils are Typic Fibrisols, with the occassional occurrence of Mesic Fibrisols. Terric Fibrisols and some Cumulo Fibrisols form a significant proportion of the soil landscape. The Terric Fibrisols appear most frequently near the boundaries of the dune areas, showing a thinning of the organic layer over the eolian material and a transition to unit 5. The Cumulo soils have thin layers (2-5 cm) of sandy eolian material between layers of organic material. These mineral layers are in total, less than 30 cm thick. Pale, marly, strongly effervescent layers are common in the fen areas in the northern half of the subdivision. One layer usually occurs around 70 cm below the surface and another at around 105 cm. These marly layers are rare in the southern half of the study area.

The fen landscape is horizontal, with faint suggestions of ribbing or patterning. During the summer of the survey several centimetres of water stood on the surface. Slopes are nearly level (0.5-2.5%).

The vegetation consists mainly of sedges and rushes, with willows and swamp birch scattered over all but the very wettest areas. The occassional larch is also present. Some of these fen areas have been cleared of brush, apparently

to provide better winter pasture; in these cases, the vegetation is mostly sedges and rushes, although the birch and willow are invading the area.

Unit 2: This unit is closely related to unit 1. It, too, is very poorly drained with Organic soils formed in fen material. However, Cumulic and Terric Fibrisols are more common than Typic Fibrisols. The unit is perhaps slightly better drained. During the time of the field investigation, the water table in the areas mapped as unit 2 was usually at the surface rather than above it. Generally, these areas are found around and between the arms of the large dunes. Areas mapped as unit 1 tend to be more remote from the dunes.

The marly layers discussed in association with the Cumulo Fibrisols in unit 1 also occur in these soils.

The landscape is horizontal, with nearly level slopes (0.5-2.5%). Any ribbing in the fens is absent. The vegetation is essentially the same as for unit 1, except that larch appears less frequently.

Unit 3: This unit includes the well-drained parabolic and longitudinal dunes areas. The dunes are stabilized, and with one exception, support a forest cover. Typically, jack pine grows on the dune crests, while a mix of aspen and

balsam poplar and black spruce are found on the sides. The shrub layer is sparse near the crests, but becomes thicker and taller down the sides. Shrubs include Saskatoon berry, wild rose, raspberry and a variety of currants. The ground cover includes bunchberry, wild lily-of-the-valley, bearberry, harebell, and grasses. In one case, part of a dune had been cleared; this now supports a mix of native and cultivated grasses and forbs.

Most dunes are about six metres high, but the dune relief ranges from 1-10 m. Slopes across the ridges are in one case, only 5% (3c) but are more often between 6 and 9% (3d) and 10 and 15% (3c). Slopes along the crest ridges are between 2 and 5%.

The dunes themselves are in the order of 400 metres long, and 250 metres wide (from the outside of one arm to the outside of the other), with the arms about 50 metres across. The dunes are oriented northwest-southeast, with the arms opening upwind to the northwest.

The dominant soils were Eluviated Eutric and Orthic Eutric Brunisols, with occasional Orthic Gray Luvisols. Textures are sandy, and structure is very weak. The surface horizon (Ae or Ahe) may be strongly acid, but the rest of the soil is usually only slightly acid.

The upper horizons (Ahe, Bm) are friable, while the lower BC horizon tends to have a firm consistence. Finer-textured reddish bands, each about a centimetre thick, are sometimes present in the BC. Free carbonates were

detected at a depth of approximately 130cm.

Unit 4: This unit is found in undulating landscapes of eolian origin. These areas have been cleared of the original forest cover, and now support a mix of grasses, clovers, and other forbs, with some wild rose and snowberry. Slopes are very gentle, from 2-5%. The unit is moderately well-drained, with a few small imperfectly drained depressions.

The soils are mostly sandy textured Orthic Eutric Brunisols, but there is also significant occurrence of Orthic Melanic Brunisols where weakly developed Ah horizons more than 10cm thick are present as a result of cultivation. Gleyed Eutric Brunisols are found in the imperfectly drained hollows, and in these cases the "gleyed" designation is due to the presence of distinct mottles within 50 cm of the surface, or to the presence of prominent mottling within 50 to 100 cm of the surface. As with the unit 3 soils, no Bt horizons could be identified.

These soils are very friable, and structure is very weak to absent. They are medium acid. The reddish clay bands were found in the BC horizons of a few soils. Carbonates were not noted above 150 cm depth.

Unit 5: This unit accounts for the intergrade region

between the well-drained areas described in unit 3 and the very wet areas described in units 1 and 2. The landscape is undulating, with nearly level slopes (0.5-2.5%). The soils in this unit are imperfectly to poorly drained. At the better-drained end of this range, the sandy eolian material has a bluish, reduced appearance within 100 cm of the surface. As conditions become wetter outward from the dunes, the organic mat at the surface thickens. Soils that occur in this unit thus progress from Gleyed Eutric Brunisols at the boundary with unit 3 to a peaty phase of Rego Gleysols at the boundaries with units 1 or 2.

The soils are sandy to loamy sand in texture. They have no structure, and are non-sticky. They are neutral in reaction, or may be carbonated nearly to the surface.

The vegetation also gradually changes from very moist balsam poplar forest with some willow, to open areas covered with sedges, grasses, and swamp birch. Currant, fireweed, bedstraw, and mosses are also present. At the foot of some of the dunes, acid-loving shrubs such as blueberry and Labrador tea are common. However, the soils are not acid, and may in fact be carbonated throughout the profile.

Unit 6: This unit includes areas of deep (more than 50 cm) open water.

Unit 7: This unit includes disturbed land such as roads and ditches.

Correlations: The well-drained soils at Meadowcrest, as mapped in unit 3 and unit 4 do not correlate with the classification of soils on sands in earlier studies. Both Bowser et al. (1962) in the Soil Survey of the Edmonton Sheet, and Pawluk and Dudas (1982), in a study some 8 km to the south found the dominant soils on sands to be Luvisols. In both cases, Bt horizons were detected, and the soils were classed in the Luvisolic order. In the mechanical analysis of a Culp Loamy Sand (Orthic Gray Luvisol) the Bt1 horizon showed an increase in total clay content of 29% over that of the Ae horizon (Bowser et al., 1962). Pawluk and Dudas (1982) found an increase in clay content of about eight percent in the illuvial horizon, sufficient to permit calling it a Bt horizon.

In the case of the Meadowcrest soils, such an increase in clay content was not found. Clay content remains at about 4% throughout the profile. If the reddish bands or lamellae occassionally found in the BC horizon had an aggregate thickness of at least 10 cm, then this horizon could be termed Bt (Canada Soil Survey Committee, 1978b). However, such was not the case. Because of the lack of a Bt horizon, the soils in this unit were placed in the Brunisolic order. Perhaps slightly more recent dune

activity in this area, or the slightly coarser texture of the eolian material at Meadowcrest, originally with a very small amount of clay-sized material to be moved through the profile, had let to the development of Brunisolic rather than Luvisolic soils. The well-drained Meadowcrest soils appear to correlate best with the Heart complex, a loose grouping of mostly Brunisolic soils developed in eolian sand.

There are no Organic or Gleysolic soils in the Edmonton report that correspond with those found at Meadowcrest. The Gleysolic soils of unit 5 do not have an equivalent in the Alberta Soil Name File[1]. The Organic soils of units 1 and 2 correlate with the Eaglesham complex, where undifferentiated Organics developed from sedge peats have been grouped (Alberta Soil Name File[1]).

[1]Alberta Soil Survey, personal communication.

4. RESULTS OF SOIL CHARACTERIZATION

Introduction

In this chapter results of the field and laboratory retention moisture flow properties, bulk density, moisture retention and Atterberg limits (plasticity) will be presented. These will be discussed on the basis of the mapping units used to describe the soils at Meadowcrest Estates and at Springhill Park.

Moisture Flow Properties

The Air-Entry Permeameter: The advantages of the AEP compared to the double-ring infiltrometer are reported to be its speed, accuracy, and low water use (Topp and Binns, 1976). This study did not set out to compare the accuracy and precision of the AEP and the double-ring infiltrometer except in a very limited way. Here, the field use aspects of the two techniques were the main considerations.

The AEP gives a much quicker result than does the double-ring infiltrometer. Once the site is prepared and the instrument is installed, a value for hydraulic conductivity can be obtained in from 15 minutes to one or two hours. However, the test cannot be immediately repeated on the same site as it can for the double-ring infiltrometer. This also means that if something goes wrong after the water is added, results often cannot be salvaged for that site. This does not present a problem if tests are

conducted at the soil surface, as the instrument is not at all difficult to move and re-install. If, though, as in the case of this study, the testing is at a level below the surface, then one must either wait for the site to dry, or dig another hole and move the AEP.

For the double-ring infiltrometer, pre-soaking of the test site is necessary, often requiring several hours for equilibrium flow to be established. Running the test itself then requires a relatively short time. The time can be controlled to a certain extent by choosing a time interval over which the outflow of water is observed, but fine-textured soils may involve two or three hours for the tests themselves.

The AEP does use much less water than the double-ring infiltrometer. On average, testing with the double-ring requires 150 L of water per site. The AEP, by contrast only requires 10 L. The size and weights of the two instruments are comparable, and they both require a number of accessory items of equipment, such as hammers to drive the rings into the ground, levels, and so on. The AEP is more easily installed by one person than the double ring, because of the design of the hammer, which distributes the force of the blow evenly around the rim of the cylinder. The double-rings can be hammered into the ground by one person with a mallet, but the presence of another person to keep the ring from bouncing on hammerimpact was found to be of great help. Also, in soils with very rapid flow, one person

could not cope with reading the instrument and maintaining the water level in the outer, buffer ring.

The AEP, in other qualities falls short of the double-ring infiltrometer. The initial moisture content of the soil to be tested is more critical for the AEP than for the double rings. The sandy soils at Meadowcrest, with their very low clay content, could not be tested with the AEP during the late summer and fall of 1980. While not saturated, the soils were moist to the touch, and coarse enough that the small tensiometer on the AEP could not maintain a detectable suction. Thus, the passage of the wetting front would go undetected. Trials earlier in the summer with Dr. Topp at a similar, nearby location when the soils were much drier, however, had given very satisfactory results.

The AEP is also less robust than the double-ring in one critical area, the tensiometer. Before each test, the tensiometer had to be purged of air and checked to ensure that it was holding a seal. The ceramic tip is held in place by a screw, with gaskets, cut from PVC tubing between the screw, the ceramic section, and the hollow metal rod. The tip can be easily broken by over-tightening the screw, or by pushing it into the ground too forcefully. Of course, the tip can also be broken by being pushed against a rock or pebble or some other hard object or layer. The gaskets become worn as the tensiometer is installed and can pull away from the tip, breaking the necessary seal. The gaskets

themselves must be cut by hand, an accomplishment requiring some practice. Overall, the AEP requires slightly more care to install and use than the double-ring, but retains the great advantage of being both less time and water demanding.

Moisture Flow Properties - Springhill Park: At Springhill, the air entry permeameter was used at sites in units 1, 2 and 3 to determine hydraulic conductivity. The other mapping units were imperfectly to very poorly drained, and were not tested.

The field measured hydraulic conductivities for the three units are given in Table 8 along with the average values for the hydraulic conductivities of cores removed from the AEP test.

The arithmetic means and geometric means of the values obtained are also listed. The geometric mean was suggested by Topp and Binns (1981) as being more applicable to use with hydraulic conductivity as it dampens the wide variability often encountered in hydraulic conductivity determinations. The geometric mean is the nth root of the individual values, or:

$$\text{geometric mean} = (X_1 X_2 X_3 \ldots X_n)^{1/n} \qquad (2).$$

where n is the number of observations, and x is the value of the observation (Zar, 1974).

In its use in this case, the geometric mean differs very little from the arithmetic for units 2 and 3. For unit 1, though, the effects of one erratic value on the

TABLE 8. Moisture Flow Properties and Bulk Densities at 50 cm for Springhill Clay-Clay Loam Luvisolic Soils

Unit/Soil	Grid Location	K_{aep} (cm/sec)	K_{core}[1] (cm/sec)	Bulk Density (g/cm^3)
1/Uncas	540 475	8.63×10^{-5}		
	280 530	5.02×10^{-5}		
	440 449	7.66×10^{-5}		
	280 570	4.85×10^{-5}		
	365 285	6.40×10^{-5}		
	284 300	3.93×10^{-5}		
	615 207	1.26×10^{-5}		
	645 207	2.22×10^{-4}		
	430 265	4.54×10^{-3}	1.62×10^{-5}	1.41
	675 585	1.07×10^{-5}	2.62×10^{-9}	1.40
	530 150	5.85×10^{-5}	3.48×10^{-6}	1.61
Arithmetic Mean		4.72×10^{-4}		
Geometric Mean		7.32×10^{-5}		
2/Tawayik	638 290	6.93×10^{-5}		
	645 333	8.54×10^{-6}	5.23×10^{-7}	
3/Cooking Lake	570 630	3.34×10^{-5}	9.95×10^{-9}	1.64
	175 439	2.46×10^{-5}	8.94×10^{-7}	1.58
	550 660	3.58×10^{-5}		
	225 315	3.99×10^{-5}	4.08×10^{-6}	1.56
	610 635	1.01×10^{-4}		
Arithmetic Mean		4.69×10^{-5}		
Geometric Mean		4.12×10^{-5}		

1 Average of three values

arithmetic mean are much reduced by using the geometric mean.

Tests were conducted at 50 cm, which for all soils in the three units would be within the Bt or BC horizons. For units 1 and 3, both developed in till, the clay content of such horizons is about 35%, while for unit 2, clay content in the Bt is about 66%. It should thus be expected, then, that K would be considerable slower for unit 2 than for units 1 or 3. This is not the case.

For unit 1, all but two of the eleven sites had hydraulic conductivities in the order of 10^{-5} cm/sec. The remaining two sites had greater rates. At least one case (2.22×10^{-4} cm/sec) showed evidence of a macro pore or channel permitting rapid flow, with bubbling through of air inside the permeameter chamber while the pressure was still increasing. At the other site (with K_{aep} of 4.54×10^{-3} cm/sec) there was no obvious problem, such as early bubbling or failure of the tensiometer. No structural cracks or fissures were obvious, nor were there any apparent textural differences. There was a suggestion, though, that the tensiometer was not able to respond fast enough, and that the wetting front had indeed passed it long before this was indicated. Without any evidence of major voids, though, the relatively rapid flow through this soil cannot be completely explained away.

By contrast, the values for the laboratory determinations show much greater variability with values

ranging from 10^{-9} to 10^{-5} cm/sec. Theoretically, they should be more variable, since they sample a smaller volume than the air-entry permeameter. The AEP thus gives a more "average" conductivity value than the cores. Large structural cracks and macropores may have been included in the AEP volume, but were purposely excluded in taking the cores.

Since the cores were taken from within the large permeameter cylinder, there may have been some compaction, especially since the soils were in a resaturated condition (Topp and Binns, 1981). By reducing pore space, this would serve to lower the obtained value of K. Another factor, probably more important than any compaction, was the swelling of clays and the sealing of fine passages to moisture flow. These cores were very difficult to saturate as required before the falling head test can be carried out. Several days of soaking were necessary. According to a mineralogical analysis of the clay fraction of a Bt horizon in an Orthic Gray Luvisol (Cooking Lake series) north of this site (Crown and Greenlee, 1978), 40 to 60% of the clay fraction consisted of smectite, a highly swelling clay. The Bt horizons of all the Luvisolic soils on till in the subdivision are very similar, and closely resemble this site in all other aspects. It is reasonable to expect that the proportion of swelling clays should be about the same for the Springhill soils. If this is so, then swelling and sealing of the flow channels is to be expected.

The values for unit 3 are very similar to those for unit 1. For the five sites sampled in unit 3, the arithmetic mean K_{aep} was 4.69×10^{-5} cm/sec, while the geometric mean was nearly the same, 4.12×10^{-5} cm/sec. The hydraulic conductivities based on the lab determinations varied between 10^{-6} and 10^{-9} cm/sec, with most in the order of magnitude of 10^{-8} cm/sec. As for unit 1, the laboratory values were much lower than the field measured values, likely for the same reasons.

Despite the high clay content of the unit 2 soils, field-measured values of K_{aep} are of the same magnitude as for units 1 and 3. This clay content would be expected to reduce the hydraulic conductivity, compared to these other units, but it apparently does not. The laboratory measurement of K_{sat} are also in the same ranges as units 1 and 3. Perhaps well-developed cracks and fissures in these strongly structured soils are contributing to permit more rapid flow than would otherwise be expected. The bulk of the flow in the other two units may well be following similar structural voids, and hence there is similarity in flow properties.

Other measurments of hydraulic conductivity, whether in the field or in the laboratory are very scarce for the soil series correlated with the Springhill soils. Bowser et al. (1962) report a constant head value for the Bt2 horizon of an Uncas loam (a Dark Gray Luvisol) at about the same depth as the Springhill measurments, at 5.6×10^{-4} cm/sec (0.8

in/hr). This is equivalent to the most common soil found in unit 1. For a Falum loam, a Dark Gray Chernozemic - Dark Gray Luvisol intergrade that corresponds to a significantly occurring soil in unit 1, the constant head value for the Bt1 was 7.1×10^{-5} cm/sec (0.1 in/hr). No constant head values were determined for the Cooking Lake Orthic Gray Luvisol that correlates with the dominant unit 3 soil.

The values are high compared to the laboratory determinations on semi-disturbed cores, and even a little high compared to the field tests. The test as carried out in the Edmonton Soil Survey, though measures hydraulic conductivity through a ground, re-packed soil sample (Hayward, 1954). Reeve et al. (1977) observe that this test is most appropriate for soils that have weak structure, and that relative rather than absolute values are being determined. The Springhill soils have strong structure, which would be destroyed using this technique. The values as listed in the Edmonton report cannot be compared with those found in this study.

Some infiltration rates obtained using the double-ring infiltrometer were determined at the surfaces of two sites with Orthic Gray Luvisols of the Cooking Lake series (Chapter III, this document). The average infiltration rate was 3.8×10^{-4} cm/sec at one site 19 km north of Springhill, and at the other, 10km east, the average was 8.8×10^{-5} cm/sec. These values are more rapid than K_{aep}. However, results of the two tests must be compared with some

reservations. According to Topp and Binns (1981), K_{aep} is about half K_{sat}. The bottom of the double-rings would reach into the AB horizons, so that the flow properties measured would be for the AB and Bt horizons. Since the AEP was installed at 50 cm, it measures flow properties in the Bt and BC.

Besides the Edmonton soil survey (Bowser et al., 1962) and the determinations discussed in Chapter III of this document, there does not appear to be any other information available on hydraulic conductivity for this suite of soils.

<u>Moisture Flow Properties - Meadowcrest Estates</u>: The principal method for determining hydraulic conductivity in this area was a constant head laboratory procedure conducted on soil cores (Table 9). Some field measurement of surface infiltration rates determined by the double-ring method (Chapter III, this document) and core-based K_{sat} values for three additional sites are included in Table 9 for comparison. Two sites corresponded to the unit 3 definition, and the other to the unit 5 definition.

For Meadowcrest unit 3, consisting of well-drained forested dune areas with Brunisolic soils, the arithmetic mean of the K_{sat} determinations was 3.93×10^{-3} cm/sec. The geometric mean was 3.77×10^{-3} cm/sec. The small difference between the two means reflect the relatively small variability in the K_{sat} values, compared to the Springhill tests. For the infiltration test sites, the K_{core} values

TABLE 9. Moisture flow Properties and Bulk Density at 50cm for Meadowcrest Brunisolic Sandy Soils

Unit/Soil	Grid Location	Saturated Hydraulic Conductivity (cm/sec) Rep 1	Rep 2	Rep 3	Ave	Surface Infiltration* (cm/sec)	Bulk Density (g/cm^3)
3/E.EB.	665 248	2.86×10^{-3}	4.52×10^{-3}	3.09×10^{-3}	3.49×10^{-3}		1.59
	587 184	2.78×10^{-3}	2.60×10^{-3}	2.70×10^{-3}	2.69×10^{-3}		1.52
	281 360	1.90×10^{-3}	2.21×10^{-3}	6.88×10^{-3}	3.66×10^{-3}		1.56
	315 591	5.41×10^{-3}	7.50×10^{-3}	4.71×10^{-3}	5.87×10^{-3}		1.59
		Unit	Arithmetic Mean		3.93×10^{-3}		
			Geometric Mean		3.77×10^{-3}		
4/O.EB.	525 555	6.28×10^{-3}	4.00×10^{-3}	5.60×10^{-3}	5.29×10^{-3}		1.52
5/R.G.	400 430	2.96×10^{-4}	7.41×10^{-3}	4.47×10^{-4}	2.72×10^{-3}		
3/D.GL.	Site 16*	2.40×10^{-3}	2.81×10^{-3}	3.69×10^{-3}	2.97×10^{-3}	1.0×10^{-2}	1.49
3/E.EB.	Site 12*	2.55×10^{-3}	3.75×10^{-3}	2.83×10^{-3}	3.05×10^{-3}	9.7×10^{-3}	1.33
5/FE.LG.	Site 15*	6.41×10^{-4}	8.22×10^{-3}	4.58×10^{-3}	6.44×10^{-3}	3.8×10^{-3}	1.57

* From Chapter III

were very close to the Meadowcrest means, one with an average of 2.97×10^{-3} cm/sec and the other with 3.05×10^{-3} cm/sec. The surface infiltration values are slightly higher, at 1.0×10^{-2} and 9.7×10^{-3} cm/sec, probably reflecting looser packing or better structure.

Discussion: In general the moisture flow properties of the sandy soils at Meadowcrest were much less variable than those for the till soils at Springhill. This was true for both the field and the laboratory techniques. This is due to the low content of silts and clays and the lack of structure in these soils.

The till soils are strongly structured with major cracks and macropores that have a large influence on water movement. They also contain higher amounts of clays that can swell and block pores. This pore blockage would be especially important in the laboratory determinations as slow saturation can result in a tightly sealed mass. This is reflected in the very low values for K_{sat} determined on cores (Table 8). The discussion suggests that laboratory techniques could be acceptable to estimate field characteristics of sandy soils, but would be questionable for clayey materials.

The other notable feature of the measurements is that hydraulic conductivity on the sands is about one hundred times the conductivity on the dense subsoils of the Cooking Lake and Uncas soils.

Other Physical Properties

The results of the tests for bulk density and moisture retention for the soils at Springhill are listed in Table 10. Bulk density and moisture retension data for the sandy Meadowcrest soils may be found in Table 11.

The bulk densities determined at Springhill and Meadowcrest (Table 10 and Table 11) tended to be higher than those for the infiltration test sites (Chapter III). At 50 cm, results for the sandy soils from the infiltration sites were between 1.33 and 1.49 g/cm^3, while for the samples collected in this study the values were between 1.52 and 1.59 g/cm^3. The latter values are more typical of other values reported for soils of this texture (Hillel, 1980). Bt horizon bulk density for a Cooking Lake site in Chapter III was 1.30 g/cm^3. For unit 3 the 50 cm bulk density (Bt horizon level) was between 1.55 and 1.58 g/cm^3. However, the effects of the hydraulic conductivity tests on the cores may have had a strong effect. Some material may have washed out of the cores, especially from the sandy soils. For the clay loam till soils swelling of the soils and then trimming the upper and lower surfaces to fit the falling head permeameter would reduce the amount of mineral material in the cores, and thus also the bulk density.

Other reported bulk density values for Cooking Lake and Uncas soils (Crown, 1977) range between 1.67-1.80 g/cm^3. These were determined on waxed clods, though, which give higher bulk density values than the core method. The till

TABLE 10. Moisture Retention for Springhill Clay Loam Luvisolic Soils at 50 cm.

Unit/Soil	Grid Location	Volumetric Moisture Content (%)		
		0 bar	1 bar	15 bar
1/Uncas	430 265	79.5**	34.4	35.1
	530 150	50.4	33.3	26.2
2/Tawayik*	638 298*	99.0**	47.9	39.2
3/Cooking Lake	175 439	65.9	36.3	34.3
	225 315	54.7	31.6	26.0

* Assumed bulk density of 1.45 g/cm^3
** Abnormally high

TABLE 11. Moisture Retention for Meadowcrest Brunisolic Sandy Soils at 50 cm.

Unit/Soil	Grid Location	Volumetric Moisture Content (%)		
		0 bar	1 bar	15 bar
3/O.EB.	665 248	55.1	8.7	6.0
	587 184	66.1	10.5	3.8
	281 360	53.5	8.9	6.2
	315 591	53.3	5.6	5.4
4/O.EB.	525 555	53.7	6.1	6.7

of the Cooking Lake moraine has been noted to be variable in its degree of compaction; this could explain the differences.

Moisture retention values for the clay soils at Springhill, are presented in Table 10. The values for the Cooking Lake and Uncas soils were very similar, while those for the Dark Gray Luvisol in lacustrine (Tawayik series) were slightly higher. Some of the 0 bar values, especially for the Tawayik soil, are very high, and are suspect.

Moisture retension values were assessed for a Cooking Lake Luvisolic sequence site (Crown and Greenlee, 1978). There, the 15 bar moisture content for the Bt horizon was 14%, while in this study it was 26 -35%. These values may seem high, but since they were determined on semi-disturbed cores, the values should be higher than those determined on ground sieved samples, as at the ISSS site.

Moisture retention values for the sandy Meadowcrest soils are presented in Table 11. These curves were all very similar, with a very sharp drop in moisture content as suction increased from zero to one bar. This is consistent with the very low silt and clay contents. At 15 bars these soils are much drier (about 6% moisture content by volume) than the Springhill soils, which have 25-30% moisture content.

The volumetric moisture content at zero bars gives a measure of the total porosity of the soil. As the suction is increased and the moisture content decreases, the change

in moisture content is equal to the total volume of pores that has drained. As suction increases further, narrower and narrower pores will be drained.

The results of the Atterberg limits trials for the Springhill soils are given in Table 12. These trials were conducted on samples from the detailed sampling sites. Also listed are the original clay contents of each horizon. Coarse sand was removed before the limits were determined.

The Cooking Lake and Uncas soils, which dominate units 3 and 1, have liquid limits at less than 50% moisture content, and plasticity indexes of less than 25 in all horizons. The Dark Gray Luvisols in the lacustrine veneer over till (Tawayik series) have higher clay contents than the till soils, and the liquid limits are at more than 60% moisture content. The plasticity indexes are greater than 45. For the Gleysolic soils in unit 5, where texture varies dramatically with depth, the strong effect that clay content has on the Atterberg limits is clearly demonstrated. In the Bg, the 60% clay content is associated with a liquid limit of 71%; in the ICg, where clay content is only 16%, the liquid limit is 24%.

Therefore, where clay content is high (Tawayik and Prestville soils), the liquid limit and plasticity index are high. Where clay content is less, LL and PI are also less. The plastic limit shows a much weaker response to clay content, since while the absorbed water layers impart plasticity, they are being held too rigidly on the clay

particles to allow the soil to flow. For example, for the unit 3 soil, clay content increases from 15% in the Ae to 33% in the Bt. The liquid limit increases at the same time from 18 to 37. The plastic limit remains constant at 14. The Ap horizons of most of the profiles have relatively high liquid and plastic limits, considering their clay contents. This can be attributed to the effects of the relatively high organic matter content of these dark surface horizons.

The well-drained units, 1, 2, and 3, are the ones most likely to have sewage disposal systems installed in them. The maximum plasticity indexes are generally associated in all these units with the Bt or BC horizons, which are also the depths at which a sewage disposal system trenches and weeping tile would be installed. The higher the plasticity index, the greater the range of moisture contents over which the soil may be puddled, and rendered much less permeable. Hence, greater care must be taken during construction on the sites with high plasticity. The soils of unit 2 will be more susceptible to such damage during system installation than the Uncas and Cooking Lake soils which dominate units 1 and 3.

TABLE 12. Atterberg Limits for Soils of Springhill Park

Unit/Soil	Horizon	Clay Content (%)	Liquid Limit %	Plastic Limit %	Plasticity Index %
1/Uncas	Ap	15	38	27	11
	Ae	33	31	16	15
	AB	41	35	15	20
	Bt	45	41	16	25
	BC	28	34	14	20
	Cca	36	41	16	25
2/Tawayik	Ap	23	63	32	31
	AB	67	73	28	45
	Bt	66	61		
	BC	66	70	25	45
	Cca	43	77	27	50
3/Cooking Lake	Ae	15	18	14	4
	AB	26	29	14	15
	Bt	33	37	14	23
	BC	33	35	16	19
	C	30	35	16	19
4/	Apg	30	64	36	28
	Btg	58	75	26	49
	BCkg	69	79	30	49
	Ccag	67	77	25	53
5/	Ah	30	42	19	23
	Bg	60	71	22	49
	ICg	16	24	16	8
	ICg	33	38	13	25

5. LAND EVALUATION FOR ON-SITE SEWAGE DISPOSAL

Application of Evaluation Systems

Using the information that has been collected for the Springhill and Meadowcrest areas, the mapping units can be rated according to the several evaluation schemes discussed in the literature review.

Table 13 rates the units at Springhill Park for effluent disposal according to the USDA regulations as outlined on pp 31-32, and also indicates the kind and severity of limitations according to the US Soil Conservation Service guidelines (Table 1). Although they do not measure water flow in the same way, hydraulic conductivities were substituted for percolation rates in the following way (U.S. Soil conservation Service, 1978):

Percolation rate	Hydraulic Conductivity
8-18 min/cm	2.5-13 cm/hr
18-24 min/cm	2.5-1.5 cm/hr

These water flow values are critical values in these evaluation systems.

For the soils at Springhill, the average values of field hydraulic conductivity have been converted from cm/sec to cm/hr as follows:

Unit/Soil	K(cm/sec)	K(cm/hr)
Unit 1/Uncas	7.32×10^{-5}	.25
Unit 2/Tawayik	2.43×10^{-5}	.08
Unit 3/Cooking Lake	4.12×10^{-5}	.14

TABLE 13. Springhill Park ratings for on-site sewage disposal - USDA and US Soil Conservation Service criteria.

Map Unit	USDA Pass	USDA Fail	Soil Conservation Service Slight	Moderate	Severe
1d-h		perm[1]	slope		perm
1d-i		"	slope		"
1e-h		"		slope	"
1e-i		"		slope	"
1e-r		"		slope	"
1f-i		perm,slope[2]			perm,slope
1f-r		perm,slope			perm,slope
2c-w		perm			perm
3c-w		perm			perm
3d-h		"	slope		"
3d-i		"	slope		"
3e-h		"		slope	"
3f-i		"			perm,slope
4b-w		WT[3]			WT
4c-u		WT			WT
5b-w		WT			WT
6b-h		WT			WT
7	N/A[4]				
8	N/A				
9	N/A				

1 unsuitable permeability
2 excessive slope
3 high seasonal or permanent water table
4 not applicable

According to the USDA criteria, all three of these units would fail to meet the standards because of slow permeability. Units 4, 5, 6, and 9 would fail because of high water tables.

Under the US Soil Conservation Service standards, all well-drained units (Units 1, 2, and 3) are severely limited by their low permeability. Units 5, 6 and 9 are also severely limited because of the presence of a seasonal high water table. The indications of gleying and mottling are not as strongly expressed in unit 4; this unit was therefore considered only moderately limited by drainage. However, permeability is likely in the same range as that for unit 2, and so unit 4 should still be considered severely limited.

Units le-h, le-i, le-r and 3e-h are moderately limited because of dominant slopes in the 9-15% range. Units 1f-r and 3f-i are severely limited by slopes exceeding 15%.

Table 14 presents the USDA and US Soil Conservation Service ratings for Meadowcrest.

The average hydraulic conductivities for soils here, when converted from cm/sec to cm/hr, are:

Unit/Soil	K(cm/sec)	K(cm/hr)
Unit 3/Heart	3.77×10^{-3}	14
Unit 4/Heart	5.29×10^{-3}	19
Unit 5/Sandy Gleysols	2.72×10^{-3}	9.8

Rates greater than 13cm/hr may present a pollution hazard if the site is in close proximity with water bodies or the water table (Coen and Holland, 1978). Since this is

TABLE 14. Meadowcrest Estates ratings for on-site sewage disposal - USDA and US Soil Conservation service criteria.

Map Unit	USDA		Soil Conservation Service		
	Pass	Fail	Slight	Moderate	Severe
1b		WT[1]			WT
2b		WT			WT
3c		perm[2]			perm
3d		"	slope[3]		perm
3e		"		slope	perm
4c		perm		WT	perm
5b		WT			WT
6		WT			flood[4]
7	N/A[5]				

1 high seasonal or permanent water table
2 unsuitably rapid permeability
3 excessive slope
4 subject of flooding
5 not applicable

the case at Meadowcrest, the rapid water flow properties must be considered a hazard in units 3 and 4. According to the USDA specifications, sites in these units would fail.

All other units also fail to meet the specifications. Unit 5 has acceptable flow properties, but it also has a high water table, as do units 1, 2 and 6.

According to the US Soil Conservation Service evaluations, units 1, 2, 5, and 6 are severely limited by the high water table. Units 3 and 4 are severely limited by the excessive permeability combined with the shallow water table. Slope also presents a moderate hazard for unit 3e.

According to Bouma (1974), many of the limiting situations can be overcome by proper construction and management. For the slowly permeable Springhill soils of units 1, 2, and 3 that are otherwise well-drained, interpretation of this paper suggests that the problems are enhanced by biological clogging and by puddling or smearing the soil during construction. A conventional trench system, he suggests, can be used, but a series of trenches should be excavated, rather than an entire bed. This will reduce the possibility of compaction of the future infiltrative surface by it being repeatedly driven over during construction. He also recommends the introduction of periods of aeration to allow the breakdown of the components of biological clogging. Still, the trench system will need to be large compared to more rapidly permeable soils.

Where the water table is never closer than 30 cm to the

surface, but less than 1.5 m, a mound system with the bed installed on top of 60 cm of fill covering the plowed surface of the original soil can be built as an alternative. This could be used in Springhill unit 4b-u and 4c-u, and possibly 5b-w. At Meadowcrest, this would be appropriate for the less well-drained parts of unit 4, and the better drained members of unit 5. Subsurface tile drainage could also be used to lower the water table.

The very wet organic mapping units at both Springhill and Meadowcrest would not be considered correctable by Bouma's criteria.

The rapidly permeable sands typified by Meadowcrest units 3 and 4 were considered to function adequately except for inadequate nitrogen removal; however, no solutions were offered to overcome this. Conventional seepage beds or trenches are recommended. Problems of excessive slope are not discussed.

The University of Minnesota guidelines (Machmeier, 1981) offer much the same solutions to the same problems, although in much greater detail.

The use of mound is recommended for situations where the water table is within 1 m of the surface (such as Springhill units 4 and 5, Meadowcrest unit 5) or where the percolation rate is greater than 47 min/cm.

For well-drained soils with percolation rates between 24 and 47 min/cm, Machmeier (1981) considers it possible to

provide excellent sewage treatment, provided careful construction practises are followed. This should be a consideration in the till and lacustrine soils of the Cooking Lake moraine. Construction must take place only when the soil moisture content is below the plastic limit, thereby avoiding any compaction, puddling or smearing of the soil that would destroy its natural structure and severely reduce it capability to accept water.

For Springhill units 1 and 3, with plastic limits at moisture contents of no greater than 18%, this may limit construction, especially in the spring. In unit 2 at Springhill, the plastic limit is about 25%, so that working these soils at higher moisture contents than those for units 1 or 3 would be permisable. However, from the moisture retention information, the unit 2 soils are also harder to dry out, so that the chances of moisture content being below the plastic limit are slightly less. Puddling and smearing will not be a problem for the Meadowcrest soils since they are non-plastic.

Where the percolation rates are rapid (between 0.05 and 2 min/cm - as in Meadowcrest units 3, 4 and 5), three techniques are suggested to maximize treatment. One is to use a layer of finer soil material between the existing soil and the crushed rock or gravel used in the trenches. Another is to encourage the development of the biological mat which will slow down infiltration and improve filtration. The third technique uses a pressure system to

evenly distribute the effluent over the entire area of the seepage bed.

The University of Wisconsin approach has taken the Bouma approach one step further. The McCormack and Johnston (1982) approach takes it a step still further, where present and future costs of a system are calculated.
However, this approach requires considerable input from government and industry sources, and its applicaton was not feasible in this study. This approach would be of great value to the consumer. It may also encourage better choice of systems, as a well-designed, trouble free systems will undoubtedly be more economical in the long run.

Discussion: This examination of the different evaluations, started with the pessimistic situation where most units in both subdivisions fail to meet the USDA standards. At Springhill, the problems were sometimes because of very slow infiltration, sometimes high water tables, and sometimes excessive slope, with the latter two in combination with slow infiltration. At Meadowcrest failures were due to high water tables, and excessively rapid infiltration which might easily allow groundwater contamination.

The US Soil Conservation Service classification permits greater breakdown of the problems that could be encountered, but still offers no solutions. At Springhill, the low permeability is such that the limitations are severe. The Meadowcrest soils are also severely limited, but by rapid

through-flow and high water table.

The most successful approach seems to be the one that identifies a problem situation and attempts to correct it, such as the Machmeier (1981) or Bouma (1974) approaches. Ideally, costs would be included, and something like the Fritton (1981) flow models could be used operatively to design the systems.

The Springhill units 1, 2, and 3 could have successful systems if the construction is very carefully carried out and if the absorption area is adequately sized. Sites in unit 4 could be made usable by raising a mound over the surface. Sites in units 5 and 6 may be correctable with a mound system, but, in general, should be avoided.

The Meadowcrest units 1 and 2 cannot be considered to be in situations that can be ameliorated, as water tables are at the surface for most of the year. Performance in unit 3 sites can be improved, again by building a mound, or alternatively by lining the trenches with finer material, or by otherwise slowing down infiltration by encouraging the development of a biological mat. Unit 4 sites could be improved in the same way, but in some situations the water table may be near enough to the surface to require that a mound be raised. Unit 5, being poorly drained, and usually having seepage within the sola probably should not be used, although raised mounds may sufficiently raise the system above the water table for safe system operation.

The soils in these subdivisions represent extreme

situations for sewage disposal in the Edmonton area. By contrast, the Chernozemic soils, discussed in Chapter III of this study, including the Angus Ridge, Beaverhills and Winterburn series with deep well-drained medium-textured soils should be able to provide excellent treatment, with little deviation from standard design and construction practices. These are highly productive soils, though, and their use for dwellings would mean their loss for agriculture.

V GENERAL CONCLUSIONS

1. The soils of the Edmonton area are highly diverse in terms of their soil development and parent materials. The hydraulic conductivities of these soils are also highly diverse. Soils with fine-textured lacustrine and residual parent materials are associated with low rates of hydraulic conductivity, infiltration, and percolation. Soils with coarse-textured fluvial and eolian materials have very rapid rates. The Luvisolic to Chernozemic sequence of soils developed on till in the Cooking Lake moraine area demonstrate the powerful effect that horizonation can have on flow properties. The Chernozemic soils permit rapid flow, while the Luvisolic soils have much lower flow rates.

2. The air-entry permeameter proved valuable in measuring hydraulic conductivity because it was fast, used much less water than the double-ring infiltrometer, and gave reproducible results. However, the AEP required careful technical application and the tensiometer tip was subject to breakage. Also, it cannot be used in very moist soils.

3. Hydraulic conductivites measured with the air-entry permeameter at Springhill were similar for all well-drained soils, with values of around 5.0×10^{-5} cm/sec. Laboratory measurements on cores gave results one to three orders of

magnitude less than the field values. This difference was attributed to strong soil structure and the presence of swelling clays. These laboratory determinations did not give a good estimate of field water behaviour for these sites.

Laboratory measurements of hydraulic conductivity on cores from the sandy Meadowcrest soils (Heart complex, with dominantly Eluviated Eutric Brunisols) averaged 3.9×10^{-3} cm/sec. These measurements agreed closely with field-measured infiltration rates. This similarity is due to the lack of structure and very low clay content of these soils. Therefore, these laboratory determinations on these soils should give a good estimate of field soil water properties.

4. Limitations for on-site sewage disposal at Springhill are due to slow permeability in fine-textured material, high water table, and steep slopes.

5. Limitations for on-site sewage disposal at Meadowcrest are due to excessively rapid permeability in combination with a widespread high water table.

6. The USDA criteria for on-site sewage disposal are of limited use in that they do not indicated that specific corrective action may be possible in some situations.

The US Soil Conservation Service units guidelines for sewage disposal recognize that corrective action may be taken in some situations, but makes no effort to dictate what action could be taken.

The most valuable approach for the homeowner would be one that defines the limiting situations and specifies the alternative corrective measures, including their initial and long term costs.

7. The important properties to consider in an evaluation are the depth of unconsolidated, well-aerated material, the moisture flow properties of the soil, the slope, and the estimated system load. Other factors that may influence construction techniques, such as the plasticity of the soil, should also be examined.

VI RECOMMENDATIONS

SEWAGE DISPOSAL RECOMMENDATIONS FOR SPRINGHILL PARK AND MEADOWCREST ESTATES

1. Springhill units 1, 2 and 3 require relatively large absorption areas for on-site sewage disposal. Careful construction is necessary because of the danger of smearing or puddling of the potential infiltrative surface.

2. Because of the frequent presence of a high water table, sites in Springhill unit 4 require the construction of disposal mounds above the surface before proper sewage disposal can be achieved.

3. Springhill units 5 and 6 should not be considered as potential sites for sewage disposal because of the extended presence of a near surface water table. If absolutely necessary, mound construction may sufficiently correct this situation.

4. Meadowcrest units 1 and 2 should not be considered to be in situations that can be safely used for sewage disposal, no matter what corrective measures are taken.

5. Meadowcrest unit 3 sites may be safely used for on-site sewage disposal if infiltration can be slowed slightly by

lining the trenches with finer material or by encouraging the development of a biological mat.

6. Meadowcrest unit 4 sites require the same infiltration slowing techniques, but at those sites with slight mottling within a metre of the surface, mound construction may be necessary.

7. Meadowcrest unit 5 sites, being poorly drained, should be avoided, but if absolutely necessary, raised mound systems may allow adequate treatment.

RECOMMENDATIONS FOR FURTHER RESEARCH

1. The development of evaluation systems that incorporate the recognition of limiting site factors with the appropriate corrective measures and their attached initial and long-term costs should be encouraged.

2. Before any such evaluation systems can be put into effect in this province, the water flow properties of Alberta soils must be better quantified and documented.

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APPENDIX 1. DOUBLE-RING INFILTROMETER AND AIR-ENTRY PERMEAMETER OPERATION

A Calibrated Water Regulator For A Double Ring Infiltrometer

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THE RINGS

Both rings of the infiltrometer, the 45 cm outer ring (b) and the 20 cm inner ring (a) were made of about 0.5 cm (1/4") wall steel pipe. The inner ring was reinforced at the top for protection against deformation. A 1.5 cm ID pipe with a set screw (a) was attached to accomodate the regulator stand.

THE PRESSURE HEAD REGULATOR - CALIBRATED CYLINDER UNIT

Description

The calibrated cylinder (d), used to read the infiltration rate, and the pressure head regulator F(E), used to maintain a constant head, form one compact unit about 100 cm high. The body of the apparatus was made from 7.5 cm diameter plexiglass tube. The 1 cm plexiglass tube (b), which interconnects both components of the unit, was extended from 1cm above the bottom of the calibrated cylinder to 1cm below the upper lid of the pressure head regulator. It passed through the central block (c) to which it was airtightly glued.

The 1cm plexiglass ventilating tube (k), used to draw air into the appartus, passed through a hole in the upper lid of the pressure head regulator and ended 1cm above the central block (c).

The central block (c) separated the calibrated cylinder from the pressure head regulator. Three "L" shaped channels are drilled in the central block. Channel (d) which served as a drained for the regulator (E) was fitted with a plug. Channels (e) and (f) serve as vents for the air spaces X_1 in the calibrated cylinder and X_2 in the regulator. Both channels were controlled by a twin, straightbore stopcock (g), which opened and closed them simultaneously (see note 2). The upper channel (e) was fitted with a piece of 1cm plexiglass tube extending from the central block to 1cm from the upper lid of the regulator. A short piece of a capillary tube was fitted to channel (f) so it would protrude about 1cm to the airspace X_1 of the calibrated cylinder. The upper lid of the regulator (E), made of 0.64 cm plexiglass, had a hole for the 1 cm ventpipe (k).

The bottom of the calibrated cylinder (D), made from a 3.8 cm plexiglass block, had two 'L' shaped channels drilled in it. Channel (h) served as an outlet, and channel (i) as an inlet which was connected to the calibrated cylinder with the reservoir (C) via a flexible hose. Both channels were

fitted with a straightbore brass stopcocks. The bore diameter should not be smaller than 0.5 cm as it determines the maximal measurable infiltration rate and the refilling time of the apparatus. The cylinder calibration was based on the ratio of its diameter to the diameter of the inner ring (A), so that 1 cm of water in the inner ring correspond to the 1 cm mark on the scale of cylinder (D). This permitted a direct reading of infiltration rate in cm/time. A large plastic bottle with partially removed bottom and fastened to the stand served well as the reservoir (C).

Function

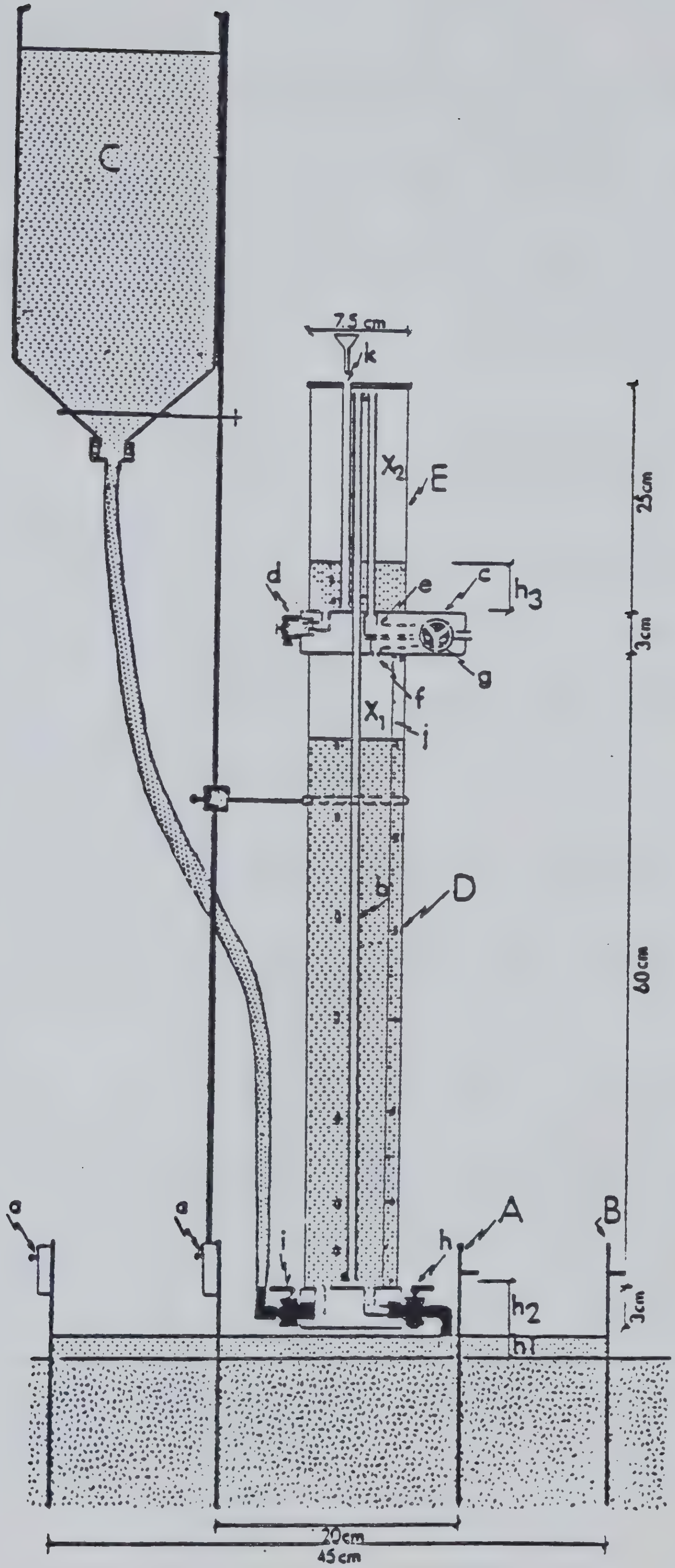
Height h1 is adjusted to cover irregularities in the ground surface (2 to 5 cm) by raising or lowering the regulator unit. Height h3 in the pressure regulator (E) is then adjusted to equal height h2 by either adding water through the air vent pipe (k) or draining water through the drain (d). Adams et al. (1957) have shown that the equilibrium H2 = h3 is the only controlling condition for the proper operation of the apparatus.

With the outlet valve (h) closed and the stopcock (g) and the inlet valve (i) open, water from the reservoir fills the calibrated cylinder. (The inlet valve (i) must be closed first and then the stopcock (g), when cylinder (D) is full).

Figure 1 shows the apparatus with the calibrated cylinder and the pressure head at equilibrium. To maintain the hydraulic head (h1) in the inner ring (A) water must be supplied from the calibrated cylinder (D) via valve (h). As water leaves the cylinder a partial vacuum is created in the airspace X_1 above the water column in the calibrated cylinder (D) - both valves (g) and (i) must be closed. The vacuum in the airspace X_1 causes air from the airspace X_2 of the pressure regulator to be sucked via connecting pipe (j) to the calibrated cylinder thus creating a partial vacuum in the airspace X_2 which must be compensaged for by air sucked from open space via vent pipe (k). Water in the inner ring rises until an equilibrium h2 = h3 is re-established.

NOTES

1. All seams as well as valves must be airtight in order to assure proper operation of the apparatus.
2. Stopcock (g) substitution - a glass stopcock with a teflon plug (Canlab 58-768-4) could be used. Teflon plug must be rebored in such a way that both channels (e and f) open and close simultaneously. All stems must be shortened. Both channels (e and f) in the central block (c) must be drilled in such a way that the spacing and diamter fits the glass stopcock. The stopcock is then fitted to the central block and secured by casting an acrylic mold around it.



A Calibrated Water Regulator for Double-Ring Infiltrometer (J. Tajek, personal communication).

Procedures for AEP Readings

1. Level soil surface at desired depth.
2. Drive appropriate cylinder into soil until approx 2" remains out.
3. Remove soil from outside cylinder for clamps - making sure clamps are between brackets on under side of lip.
4. Drive cylinder in remaining distance leaving about 0.5 cm between soil and top of cylinder.
5. Locate high spot on cylinder (for location of air escape valve).
6. Measure distance from a) ground level to soil surface
   b) soil surface to top of cylinder
7. Tamp soil around inner edge of cylinder with 1/4" diameter rod.
8. Place reservoir on cylinder making sure air escape valve is at the high spot (step 5) and tighten clamps.
9. Push tensiometer into soil to predetermined depth and allow reading to stabilize.
10. With air escape valve open - open inflow valve.
11. When air has finished coming out close escape valve and open valve to air-entry gauge.
12. Record rate of inflow of water until front reaches tensiometer.
13. Close inflow valve.
14. Wait for and obtain maximum reading on air entry gauge.
15. Close air entry valve to prevent accumulation of air in system.
16. Calculate air-entry value and conductivity using the following equations

$$Pa = -Pmin + G + L$$

$$K = \frac{dH}{dt} \times \Delta Z \times \frac{Rr^2}{Rc^2} / H_2 + Z - 1/2Pa)$$

where Pa is air-entry value
Pmin - minimum pressure head in cm (H_2O) as determined by the max reading on the vacuum gauge (air-entry)
G - height of gauge above soil surface in cm
ΔZ - depth to wet front in cm
dH/dt = rate of fall of water level in reservoir just before closing supply valve
H_2 = height above soil surface of water level in reservoir at time supply valve is closed
Rr = radius of reservoir
Rc = radius of cylinder.

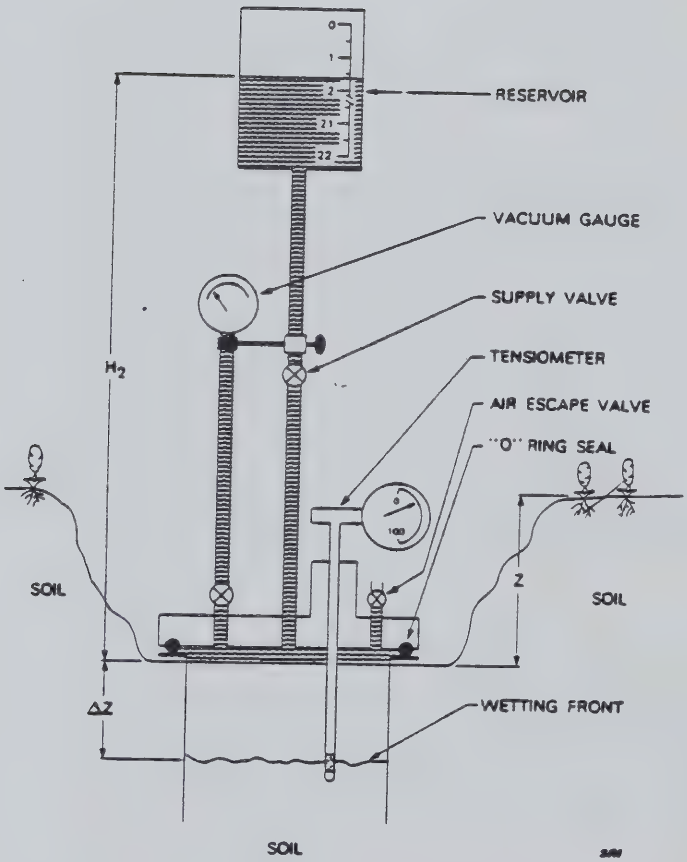


Diagram showing components of the air-entry permeameter (after Topp and binns, 1976).

APPENDIX 2. SOIL DESCRIPTIONS AND ANALYTICAL DATA FOR SPRINGHILL PARK

Map Unit 1 - Springhill

Location:	Grid reference 279 531; site 85
Landform:	Hummocky moraine
Slope and Aspect:	10-15%, complex, upper slope, west
Estimated Drainage:	Well-drained
Surface Runoff:	Rapid
Parent Material:	Calcareous clay loam till
Vegetation:	Mixed domestic grasses
Classification:	Dark Gray Luvisol
Series Correlation:	Uncas

Horizon	Depth (cm)	Description
Ap	0-15	Very dark gray (10 YR 3/1m) loam to sandy loam; moderate medium granular; friable; clear wavy boundary; 15-17 cm thick.
Ob	15-16	Moderately decomposed organic material consisting of grasses and roots; abrupt broken boundary; 0-2 cm thick.
Ae	16-23	Grayish brown (10 YR 5/2m) loam; strong medium platy; firm; clear wavy boundary; 7-10 cm thick.
AB	23-42	Light brownish gray to light yellowish brown (2.5Y 6/3m) clay loam; strong medium blocky; firm; gradual wavy boundary; 18-23 cm thick.
Bt1	42-65	Grayish brown to light olive brown (2.5Y 5/3m) clay loam; moderate coarse prismatic and strong medium blocky; firm; gradual wavy boundary; 20-25 cm thick.
Bt2	65-90	Grayish brown (2.5Y 5/2m) exped, and dark brown (10YR 4/3m) crushed colors; clay loam; moderate coarse prismatic and moderate coarse blocky; firm; many thin clayskins on void surfaces and ped faces; gradual smooth boundary; 25 cm thick.
BC	90+	Dark grayish brown (2.5Y 4/2m) clay loam; massive; firm.

Analytical Data for Site 85; Springhill Mapping Unit 1

Horizon	Part Size Dist. (<2mm)			Particles >2mm	pH	Atterberg Limits		
	Sand	Silt	Clay		$CaCl_2$	Liquid Limit	Plastic Limit	Plasticity Index
	%			%				
Ap	51	31	18	1.9	5.0	44.5	35.1	9.4
Ob	--	--	--	---	---	----	----	---
Ae	40	45	15	1.5	5.3	21.3	16.9	4.4
AB	40	37	23	1.9	4.9	38.4	17.1	11.3
Bt1	41	23	36	2.8	4.4	38.1	15.2	22.9
Bt2	41	23	36	1.5	4.3	36.7	16.2	20.5
BC	43	23	34	2.2	4.5	37.0	17.6	19.4

Map Unit 2 - Springhill

Location:	Grid reference 650 330; site 53
Landform:	Hummocky moraine
Slope and Aspect:	2-5%, upper, west
Estimated Drainage:	Well-drained
Surface Runoff:	Moderate to rapid
Parent Material:	Calcareous, silty clay till
Vegetation:	Brome grass, timothy, strawberry, dandelion
Classification:	Dark Gray Luvisol
Series Correlation:	Tawayik

Horizon	Depth (cm)	Description
Ap	0-17	Dark grayish brown (10YR 4/2m) silt loam; strong medium granular; slightly sticky; clear wavy boundary; 16-19 cm thick.
AB	17-33	Yellowish brown (10YR 5/4m) clay; strong fine blocky; sticky; gradual wavy boundary; 15-18 m thick.
Bt	33-62	Brown (10YR 5/3m) clay; strong coarse prismatic and strong medium blocky; sticky; gradual wavy boundary; 28-32 cm thick.
BC	62-75	Dark grayish brown (2.5Y 4/2m) clay; weak fine blocky; sticky; abrupt wavy boundary; 12-16 cm thick.
Cca	75+	Dark gray to dark grayish brown (2.5Y 4/1m) silty clay; massive; sticky; moderately effervescent.

Analytical Data for Site S3; Springhill Mapping Unit 2

Horizon	Part Size Dist. (<2mm)			Particles >2mm	pH	Atterberg Limits		
	Sand	Silt	Clay		$CaCl_2$	Liquid Limit	Plastic Limit	Plasticity Index
		%		%				
Ap	15	62	23	1.0	5.5	62.8	31.9	30.9
AB	13	20	67	trace	4.3	73.0	27.9	45.1
Bt	16	18	66	trace	6.4	60.5		
BC	8	26	66	trace	6.6	69.8	25.2	44.6
Cca	9	48	43	trace	---	76.8	26.8	50.0

Map Unit 3 - Springhill

Location:	Grid reference 620 625; site 95
Landform:	Inclined surface in hummocky moraine
Slope and Aspect:	10-15%, upper, north
Estimated Drainage:	Well-drained
Surface Runoff:	Medium to rapid
Parent Material:	Clay loam to sandy clay loam till
Vegetation:	Aspen and balsam poplar forest; dogwood and highbush cranberry; lungwort, wild lily of the valley, strawberry
Classification:	Orthic Gray Luvisol
Series Correlation:	Cooking Lake

Horizon	Depth (cm)	Description
LFH	8-0	Black to very dark brown (7.5YR 2/1m) partly decomposed leaves and stems.
Ahc	0-13	Very dark gray brown (7.5YR 3/1m) sandy loam; weak coarse granular; friable;clear wavy boundary; 10-14 cm thick.
Ae	13-28	Grayish brown (2.5Y 5/2m) sandy loam; moderate medium platy; friable; clear wavy boundary; 12-17 cm thick.
AB	28-41	Grayish brown (10YR 5/2m) sandy clay loam; moderate medium blocky; gradual smooth boundary; 12-15 cm thick.
Bt	41-66	Dark yellowish brown (10YR 4/4m) clay loam; moderate coarse prismatic and strong medium blocky; firm; gradual wavy boundary; 20-28 cm thick.
BC	66-110	Dark grayish brown to olive brown (2.5Y 4/3m) sandy clay loam; moderate coarse prismatic and strong medium blocky; firm; 50-56 cm thick.
C	110+	Dark grayish brown (10YR 4/2m) clay loam to sandy clay loam; massive; hard.

Analytical Data for Site 95; Springhill Mapping Unit 3

Horizon	Part Size Dist. (<2mm) Sand	Silt	Clay	Particles >2mm	pH $CaCl_2$	Atterberg Limits Liquid Limit	Plastic Limit	Plasticity Index
	%	%	%	%				
LFH	--	--	--	---	---			
Ahe	62	27	11	6.3	5.0		N.P.*	
Ae	59	25	16	4.6	4.8	17.6	14.1	3.5
AB	52	20	28	7.6	5.1	29.3	14.0	15.3
Bt	43	23	34	2.5	4.4	36.9	14.3	22.6
BC	50	16	34	2.1	4.8	35.0	15.5	19.5
C	44	26	30	1.3	7.4	34.5	15.9	18.6

*N.P. - non-plastic

Map Unit 3 - Springhill

Location:	Grid reference 210 305; site S10
Landform:	Inclined
Slope and Aspect:	10-15%, upper, south
Estimated Drainage:	Well-drained
Surface Runoff:	Moderate to rapid
Parent Material:	Calcareous, clay loam till
Vegetation:	Aspen and balsam poplar canopy; with hazelnut and wild rose, and grasses.
Classification:	Orthic Gray Luvisol
Series Correlation:	Cooking Lake

Horizon	Depth (cm)	Description
LFH	10-0	Slightly to moderately decomposed leaves, grasses and roots; abrupt wavy boundary; 5-10 cm thick.
Ahe	0-5	Very dark brown (10YR 2/2m) sandy loam; weak fine platy; friable; clear wavy boundary; 3-8 cm thick.
Ae	5-18	Light brownish gray (10YR 6/2m) loam; moderate coarse platy; friable; abrupt wavy boundary; 12-16 cm thick.
AB	18-28	Dark grayish brown to olive brown (2.5YR 4/3m) clay loam; moderate medium blocky; firm; gradual wavy boundary; 11-15 cm thick.
Bt	28-51	Dark grayish brown (2.5YR 4/2m) clay loam; strong coarse prismatic and strong medium blocky; firm; gradual wavy boundary; 43-45 cm thick.
BC	51-100	Dark grayish brown to olive brown (2.5Y 4/3m) clay loam; strong coarse primatic and strong medium blocky; firm; gradual wavy boundary
C	100+	Olive brown (2.5Y 3/3m) clay loam; massive; very hard.

Analytical Data for Site S10; Springhill Mapping Unit 3

Horizon	Part Size Dist. (<2mm) Sand	Silt	Clay	Particles >2mm	pH $CaCl_2$	Liquid Limit	Atterberg Limits Plastic Limit	Plasticity Index
	%	%	%	%				
LFH	--	--	--	---	---	---	---	---
Ahe	--	--	--	---	---	---	---	---
Ae	41	45	14	3.0	5.5	20.1	15.4	4.7
AB	40	27	33	6.6	5.5	34.7	16.4	18.3
Bt	42	21	37	1.6	5.5	41.2	18.0	23.2
BC	39	23	38	3.8	5.1	43.1	18.2	24.9
C	42	26	32	2.9	5.2	37.4	16.5	20.9

Map Unit 4 - Springhill

Location:	Grid reference 630 348; site 5
Landform:	Undulating
Slope and Aspect:	0.5-2%, toe,west
Estimated Drainage:	Poorly drained
Surface Runoff:	Moderate to slow
Parent Material:	Lacustrine
Vegetation:	Grasses, sedges, potentilla
Classification:	Humic Luvic Gleysol
Series Correlation:	Prestville

Horizon	Depth (cm)	Description
Apg	0-15	Blay (10YR 2/1m) clay loam; moderate fine blocky; slightly sticky; clear wavy boundary; 14-16 cm thick.
Btg	15-34	Very dark gray (10YR 3/1m) clay matrix; moderate fine blocky; sticky; common medium prominent dark yellowish brown (10YR 4/6m) mottles; clear wavy boundary; 18-21 cm thick.
BCkg	34-78	Gray (2.5Y 5/1m) clay; moderate fine subangular blocky; sticky; many medium prominent olive brown (2.5Y 4/6m) mottles; weak effervescence with 10% HCl; diffuse wavy boundary; 44 cm thick.
Ccag	78+	Gray (2.5Y 5/1m) clay; weak fine subangular blocky; sticky; many medium prominent yellowish brown (10YR 5/6m) mottles.

Analytical Data for Site 5; Springhill Mapping Unit 4

Horizon	Part Size Dist. (<2mm)			Particles >2mm	pH	Atterberg Limits		
	Sand	Silt	Clay		$CaCl_2$	Liquid Limit	Plastic Limit	Plasticity Index
	%			%				
Apg	33	37	30	trace	6.4	63.8	35.6	28.2
Btg	15	27	58	trace	6.2	75.2	25.6	49.6
BCkg	8	23	69	trace	6.8	78.8	30.3	48.5
Ccag	13	20	67	trace	---	77.4	24.7	52.7

Map Unit 5 - Springhill

Location:	Grid reference 650 230; site S6
Landform:	Undulating
Slope and Aspect:	2-5%, lower, north
Estimated Drainage:	Poorly drained
Surface Runoff:	Slow to ponded
Parent Material:	Fluvial-lacustrine
Vegetation:	Aspen, alder, grasses, and sedges
Classification:	Orthic Gleysol
Series Correlation:	No equivalent

Horizon	Depth (cm)	Description
Om	16-0	Very dark brown to black (7.5YR 2/1m) organic material consisting of moderately decomposed leaves, grasses, sedges materials.
Ahg	0-4	Black (2.5Y 2/1m) loam; weak medium platy; non-sticky; few fine distinct brown to dark brown (10YR 4/3m) mottles; abrupt wavy boundary; 4-5 cm thick.
Bg	4-16	Grayish brown (2.5Y 5/2m) sandy loam; massive; non-sticky; common medium prominent dark yellowish brown (10YR 4/6m) mottles; clear wavy boundary; 10-15 cm thick
Ccag	16+	Gray to light gray (2.5Y 6/1m) clay; weak fine granular; non-sticky; common medium prominent yellowish brown (10YR 5/8m) mottles; moderate effervescence; seepage at 39 cm.

Analytical Data for Site S6; Springhill Mapping Unit 5

Horizon	Part Size Dist. (<2mm) Sand	Silt	Clay	Particles >2mm	pH $CaCl_2$	Atterberg Limits Liquid Limit	Plastic Limit	Plasticity Index
	%	%	%	%				
Om	--	--	--	--	---	---	---	---
Ahg	47	31	22	trace	7.3	40.6	20.1	20.5
Bg	62	22	16	6.5	7.0	38.9	15.7	23.2
Ccag	34	33	43	2.3	---	47.6	14.4	33.2

Map Unit 6 - Springhill

Location:	Grid reference 580 560; site S2
Landform:	Undulating
Slope and Aspect:	2-5%, depressional
Estimated Drainage:	Very poorly
Surface Runoff:	Ponded
Parent Material:	Organic over lacustrine
Vegetation:	Sedges, reeds, arrow-leaved coltsfoot
Classification:	Terric Mesisol
Series Correlation:	Eaglesham complex

Horizon	Depth (cm)	Description
Om1	0-13	Reddish brown (5YR 4/3) organic material consisting of decomposed sedges, grasses and reeds, Von Post 3.
Om2	13-48	Black (5YR 2/1m) organic material consisting of moderately decomposed sedges, grasses and reeds; Von Post 5.
Ahg	48-67	Very dark gray (10YR 3/1m) silt loam; massive; sticky; gradual wavy boundary; 19-20 cm thick.
Cg	+67	Dark gray (10YR 4/1m) sandy clay loam; massive; slightly sticky.

Analytical Data for Site S2; Springhill Mapping Unit 6

Horizon	Part Size Dist. (<2mm) Sand	Silt	Clay	Particles >2mm	pH $CaCl_2$	Liquid Limit	Atterberg Limits Plastic Limit	Plasticity Index
	%	%	%	%				
Om1	--	--	--	--	---			
Om2	--	--	--	--	---			
Ahg	32	52	16	trace	4.2			
Cg	49	26	25	1.3	4.4	29.3	16.4	12.9

APPENDIX 3 SOIL DESCRIPTIONS AND ANALYTICAL DATA FOR MEADOWCREST ESTATES

Map Unit 1 - Meadowcrest

Location:	Grid reference 680 710;
Landform:	Bowl
Slope and Aspect:	.5-2%
Estimated Drainage:	Very poorly, 5cm standing water at surface
Surface Runoff:	Ponded
Parent Material:	Fen
Vegetation:	Larch, swampbirch, willow, sedge, rush
Classification:	Typic Fibrisol
Series Correlation:	No equivalent

Horizon	Depth (cm)	Description
Ofk1	0-10	Brown (10YR 5/3m) weakly decomposed organic material of fed origin; Von Post 4; strongly effervescent.
Ofk2	10-25	Dark brown (7.5YR 3/3m) very weakly decomposed organic material of fen origin, Von Post 3; mildly effervescent.
Ofk3	25-55	Brown (10YR 5/3m) weakly decomposed organic material of fen orgin; von Post 4; strongly effervescent.
Of1	55-70	Dark brown (7.5YR 3/3m) very weakly decomposed organic material of fen origin; Von Post 3; no effervescence.
Ofk4	70-85	Brown to dark brown (10YR 4/3m) weakly decomposed organic material of fen origin; Von Post 4; strongly effervescent.
Of2	85-95	Dark brown (7/5YR 3/3m) very weakly decomposed organic material of fen origin; Von Post 3; no effervescence.
Of3	95-110	Dark brown (7/5YR 3/2m) very weakly decomposed organic material of fen origin; Von Post 3; no effervescence.
Ofk5	110+	Pale brown (10YR 6/3m) weakly decomposed organic material of fen origin; Von Post 4; strongly effervescent.

Map Unit 2 - Meadowcrest

Location:	Grid reference 295 430
Landform:	Horizontal
Slope and Aspect:	0-0.5%
Estimated Drainage:	Very poorly
Surface Runoff:	Ponded
Parent Material:	Fen
Vegetation:	Willow, swampbirch, sedge, rush
Classification:	Cumulo Fibrisol
Series Correlation:	No equivalent

Horizon	Depth (cm)	Description
Of1	0-16	Black (5YR 1.7/1m) very weakly decomposed organic material of fen origin; Von Post 3; no effervescence.
Of2	16-20	Brown to dark brown (7.5YR 4/2cm) undecomposed organic material of fen origin; Von Post 1; no effervescence.
Of3	20-67	Black (10YR 1.7/1m) very weakly decomposed organic material of fen orgin; Von Post 3; no effervescence.
Cgk1	67-71	Very dark greyish brown (2.5Y 3/2m) marl; structurless; non-sticky; strongly effervescent.
Of4	71-87	Black (2.5Y 2/1m) weakly decomposed organic material of fen origin; Von Post 4; no effervescence.
Cgk2	87-95	Olive brown (2.5Y 5/3m) marl; structureless; non-sticky; strongly effervescence.
Om	95-+120	Black (2.5Y 3/1m) moderately decomposed organic material of fen origin; Von Post 6; no effervescence.

Map Unit 3 - Meadowcrest

Location:	Grid reference 665 248, Site MerA
Landform:	Ridged
Slope and Aspect:	6-9%, crest, north
Estimated Drainage:	Rapid
Surface Runoff:	Moderate
Parent Material:	Eolian
Vegetation:	Pine, spruce, aspen, grasses, wild lily-of-the-valley, yarrow, anemone, bedstraw
Classification:	Eluviated Eutric Brunisol
Series Correlation:	No equivalent

Horizon	Depth (cm)	Description
LFH	2-0	Very dark brown (7.5YR 2/1m) organic layer, consisting of fresh and moderately decomposed leaves, pine and spruce needles, grasses and stems.
Ahe	0-2.5	Dark reddish brown (5YR 3/2m) sand; structureless, single-grained; non-sticky; clear smooth boundary; 1-3 cm thick.
Bm	2.5-16.5	Brown to dark brown (7.5YR 4/4m) sand; structureless, single-grained; non-sticky; gradual wavy boundary; 13-15 cm thick.
BC1	16.5-46.5	Olive brown (2.5YR 4/4m) sand; structureless, single-grained; firm; many reddish bands, 0.5 cm thick, of finer loamy material; gradual wavy boundary; 28-35 cm thick.
BC2	46.5+	Yellowish brown (10YR 5/4m) sand; structureless, single grained; firm; with reddish bands (7.5YR 4/4m) 0.5 cm thick, of finer loamy material.

Analytical Data for Meadowcrest Mapping Unit 3, Site Mcr. A

Horizon	Part Size Dist. (<2mm) Sand (C-M-F)	Silt	Clay	Particles >2mm	pH $CaCl_2$
LFH	--	--	--	--	---
Ahe	(14-35-42) 91	5	4	0.0	5.0
BM	93	3	4	0.0	6.6
BC1	(18-37-39) 94	2	4	0.0	6.1
BC2					6.5

Map Unit 4 - Meadowcrest

Location:	Grid reference 525 555, Site PS4
Landform:	Undulating
Slope and Aspect:	2-5%, midslope, north
Estimated Drainage:	Moderately well - imperfectly
Surface Runoff:	Medium to slow
Parent Material:	Eolian
Vegetation:	Mixed native and domestic grasses, forbs such as dandelion, goldenrod, alfalfa, red and white clover
Classification:	Orthic Eutric Brunisol
Series Correlation:	No equivalent

Horizon	Depth (cm)	Description
Ap	0-13	Brown to dark brown (10YR 4/3m) sand; structureless, single-grained; non-sticy; clear wavy boundary; 10-15 cm thick.
Bm	13-28	Dark yellowish brown (10YR 4/6m) sand; structureless, single-grained; non-sticky; clear wavy boundary; 13-18 cm thick.
BC	28-60	Yellowish brown (10YR 5/4m) sand; structureless, single-grained; non-sticky; with horizontal reddish bands 1 cm thick of finer, loamy material; clear wavy boundary; 29-35 cm thick.
BCgj	60+	Pale brown (10YR 6/3m) sand; structureless, single-grained; common coarse faint yellowish brown (10YR 5/4m) mottles.

Analytical Data for Meadowcrest Mapping Unit 4, Site PS4

Horizon	Part Size Dist. ($<2mm$) Sand (C-M-F)	Silt	Clay	Particles $>2mm$	pH $CaCl_2$
Ap	91	5	4	0	6.3
Bm					5.5
BC	(2-39-53) 94	2	4	0	5.9
C	(3-47-45) 95	1	3	0	5.7

Map Unit 5 - Meadowcrest

Location:	Grid reference 680 420, Site PS2
Landform:	Ridged
Slope and Aspect:	10-15%, toe, southwest
Estimated Drainage:	Poorly drained
Surface Runoff:	Slow
Parent Material:	Eolian
Vegetation:	Willow, dogwood, wild rose, horsetail, dandelion, vetch, Canada hawkweed.
Classification:	Orthic Gleysol
Series Correlation:	No equivalent

Horizon	Depth (cm)	Description
Om	15-0	Black to very dark brown (7.5YR 2/1m) moderately decomposed organic material consisting mainly of leaf litter.
Ah	0-4	Grayish brown (10YR 5/2m) loamy sand; structureless, single-grained; non-sticky; clear wavy boundary; 3-6 cm thick.
Bg	4-29	Dark gray to dark brown (7.5YR 4/1m) sand; structureless, single-grained; non-sticky; gradual wavy boundary; 20-27 cm thick.
BCg	29-56	Dark gray (10YR 4/1m) sand; structureless, single-grained; gradual wavy boundary; 25-30 cm thick.
Cg	56+	Gray (5Y 5/1m) loamy sand; structureless, single-grained; seepage at 59 cm.

Analytical Data for Meadowcrest Mapping Unit 5, Site PS2

Horizon	Part Size Dist. (<2mm) Sand (C-M-F)	Silt	Clay	Particles >2mm	pH $CaCl_2$
Om	--	--	--	---	---
Ahe	86	6	8	0.0	7.4
Bg	89	4	7	0.0	7.2
BCg	89	2	9	0.0	6.8
Cg	85	5	10	0.0	7.2

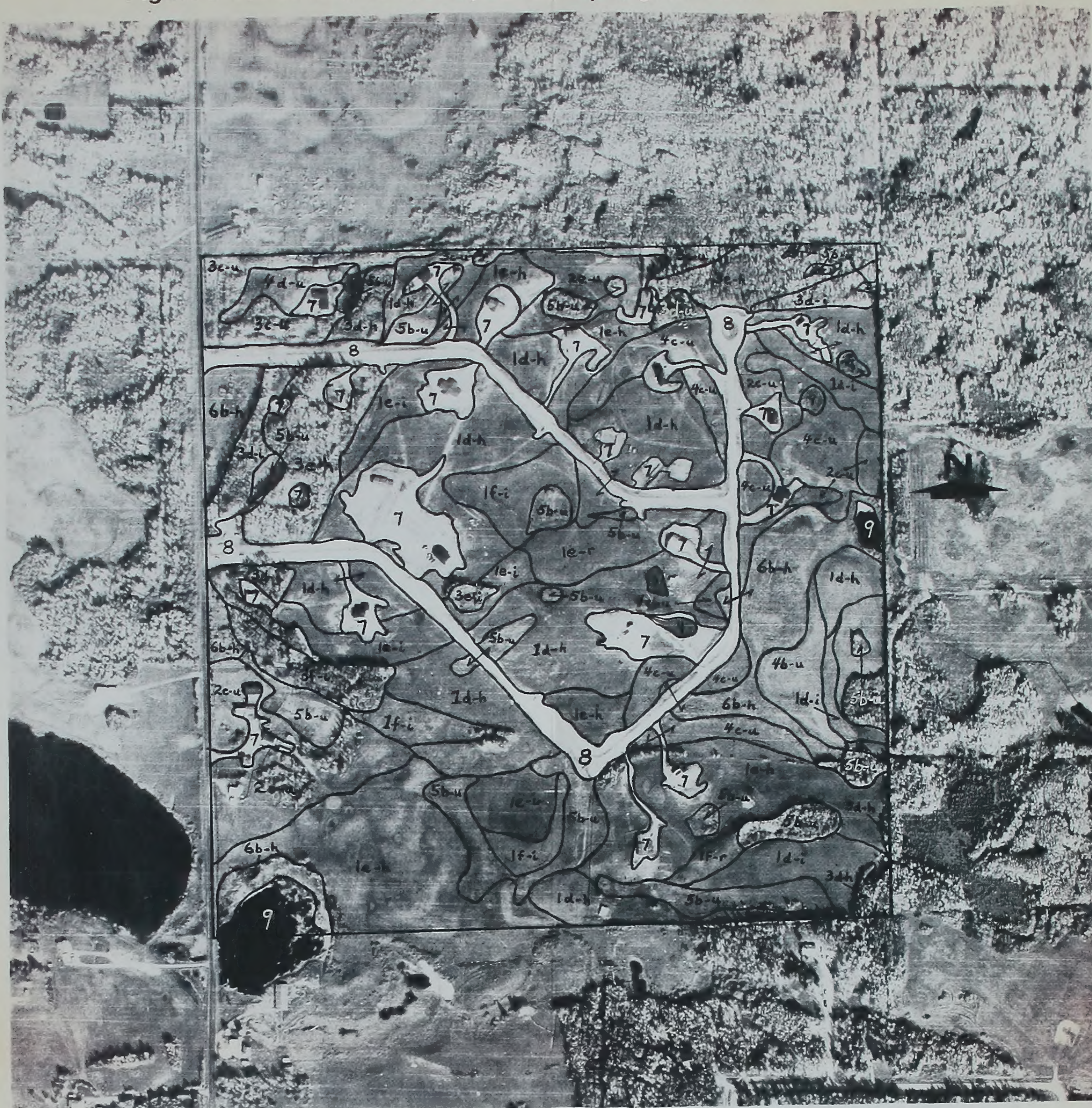
Figure 7 . Soils and landscapes of Meadowcrest Estates.

LEGEND - SOILS AND LANDSCAPES OF MEADOWCREST ESTATES (NE24 - 51-27-W4)

Scale 1:5000

Unit	Parent Material	SOIL SUBGROUP Dominant	Significant	Landform	Slope	Drainage	Vegetation
1b	Organic (fen)	Typic Fibrisol	Terric Fibrisol	Horizontal to ribbed	0.5-2.5%	Very poorly	larch, swamp birch, sedges and rushes
2b	Organic (fen)	Cumulo Fibrisol	Terric Fibrisol	Horizontal	0.5-2.5%	Very poorly	swamp birch, larch, sedges and rushes
3c	Eolian	Eluviated Eutric Brunisol	Orthic Eutric Brunisol	Undulating	2.0-5.0%	Moderately well	pine-spruce forest
3d	Eolian	Eluviated Eutric Brunisol	Orthic Eutric Brunisol	Ridged	6.0-9.0%	Well drained	pine-spruce forest and cleared, grassy
3e	Eolian	Eluviated Eutric Brunisol	Orthic Eutric Brunisol	Ridged	10-15%	Well drained	pine-spruce forest
4c	Eolian	Orthic Eutric Brunisol	Orthic Melanic Brunisol Gleyed Eutric Brunisol	Undulating	2.0-5.0%	Moderately well-imperfectly	mixed grasses and forbs
5b	Eolian	Orthic Gleysol	Orthic Humic Gleysol Gleyed Eutric Brunisol	Undulating	0.5-2.5%	Poorly-imperfectly	balsam poplar, black spruce, willow forest
6	Semi-permanent open water						
7	Disturbed land - roads, ditches						

Figure6 . Soils and landscapes of Springhill Park.



LEGEND - SOILS AND LANDSCAPES OF SPRINGHILL PARK (NW5 - 52-22-W4)

Scale 1:5000

Unit	Parent Material	SOIL SUBGROUP Dominant	Significant	Landform	Slope	Drainage	Vegetation
1d-h	Morainal	Dark Gray Luvisol	Orthic Dark Gray	Hummocky	6-9%	Well drained	grasses, forbs
1d-i	Morainal	Dark Gray Luvisol	Orthic Dark Gray	Inclined	6-9%	Well drained	grasses, forbs
1e-h	Morainal	Dark Gray Luvisol	Orthic Dark Gray	Hummocky	10-15%	Well drained	grasses, forbs
1e-i	Morainal	Dark Gray Luvisol	Orthic Dark Gray	Inclined	10-15%	Well drained	grasses, forbs
1e-r	Morainal	Dark Gray Luvisol	Orthic Dark Gray	Ridged	10-15%	Well drained	grasses, forbs
1f-i	Morainal	Dark Gray Luvisol	-	Inclined	16-30%	Well drained	grasses, forbs
1f-r	Morainal	Dark Gray Luvisol	-	Ridged	16-30%	Well drained	grasses, forbs
2c-u	Lacustrine blanket over morainal	Dark Gray Luvisol	Orthic Dark Gray	Undulating	2.5-5.0%	Moderately well	grasses, forbs
3c-u	Morainal	Orthic Gray Luvisol	Gleyed Gray Luvisol	Undulating	2.5-5.0%	Moderately well-imperfectly	aspen forest
3d-h	Morainal	Orthic Gray Luvisol	-	Hummocky	6-9%	Well drained	aspen forest
3d-i	Morainal	Orthic Gray Luvisol	-	Inclined	6-9%	Well drained	aspen forest
3e-h	Morainal	Orthic Gray Luvisol	Gleyed Gray Luvisol	Hummocky	10-15%	Well-imperfectly	aspen forest
3f-i	Morainal	Orthic Gray Luvisol	-	Inclined	16-30%	Well drained	aspen forest
4b-u	Lacustrine blanket over morainal	Humic Luvic Gleysol	Gleyed Dark Gray	Undulating	0.5-2.5%	Poorly - imperfectly	grasses, forbs
4c-u	Lacustrine blanket over morainal	Humic Luvic Gleysol	Gleyed Dark Gray	Undulating	2-5%	Poorly - imperfectly	grasses, forbs
5b-u	Fluvial lacustrine	Orthic Humic Gleysol	Fera Luvic Gleysol	Depressional	0.5-2.5%	Poorly	forested or cleared
6b-h	Organic (fen)	Terric Mesisol	Rego Gleysol, peaty phase	Horizontal	0.5-2.5%	Very poorly	sedges, rushes, grasses
7	Land disturbed for dwellings, yards and driveways.						
8	Main road.						
9	Standing water bodies - ponds, lakes, dugouts.						